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DEPARTMENT OF THE ARMY TECHNICAL MANUAL

GAS GENERATING

HEADQUARTERS, DEPARTMENT OF THE ARMY

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TECHNICAL MANUAL
No. 5-351

HEADQUARTERS
DEPARTMENT OF THE ARMY
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GAS GENERATING

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CHAPTER I

PRINCIPLES OF GAS GENERATION

Section I. INTRODUCTION

1. Purpose and Scope

a. This manual is a guide for personnel responsible for the operation of all types of industrial gas and liquid refrigerant generating, storage, and distribution equipment in use by the Army. This manual covers all such equipment, including that for generating oxygen and liquid oxygen, nitrogen and liquid nitrogen, carbon dioxide, hydrogen, and acetylene. The basic theories of various processes, plant layout, production techniques, and handling of compressed gases are covered. Wherever possible, common techniques have been grouped. Detailed operation and maintenance instructions are not included since they are covered in specific equipment manuals. Safety precautions and protective measures, including fire fighting, for the different gases and liquids are described in the chapters where they apply.

b. The material contained herein is applicable to both nuclear and nonnuclear warfare.

2. Changes or Corrections

Users of this manual are encouraged to submit comments or recommended changes to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be forwarded direct to Commandant, United States Army Engineer School, Fort Belvoir, Virginia.

Section II. PRINCIPLES OF GASES

3. Introduction

This section reviews the basic principles of the physical sciences pertaining to gases and liquids. These principles determine the design and function of gas-generating plants and of plants generating liquid oxygen and nitrogen.

4. Physical Sciences

The physical sciences of chemistry and physics are closely related. Physics includes the study of matter, energy, heat, and the expansion of gases; chemistry includes the basic elements and describes the properties of chemical change and the associated techniques required to use chemical equations. These subjects as they pertain to an understanding of gas generation and the basic equipment are briefly discussed below.

5. Physics

The physics used in this manual is concerned mainly with the structure and behavior of matter and the classes and forms of energy.

6. Chemistry

Chemistry is the science dealing with the composition of substances, and of the transformations which they undergo. It is divided into organic chemistry and inorganic chemistry. Organic chemistry is the chemistry of the hydrocarbons and their derivatives (or, which is almost the same, of carbon compounds) whether found in organisms or not. Inorganic chemistry treats of all other compounds and of the elements.

7. Physical and Chemical Changes

A change in matter wherein the composition of the matter remains the same is called a physical change while one in which the nature and composition are affected is called a chemical change. The freezing of water and making of dry ice are examples of the former while the burning of fuel or gasoline is an everyday example of the latter. In many physical changes and in all chemical changes energy is involved, being either absorbed (endothermic reaction) or liberated (exothermic reaction). Thus chemical changes involve energy changes.

8. Reaction Rate

A chemical change or the tendency of a substance to undergo a reaction as outlined above may be speeded up. This may be done by reducing the size of the particles in the reaction, by applying additional heat, by mixing, by increasing concentration, or by adding small amounts of certain specific substances called catalysts which change the rate of reaction without themselves being altered. It is also true that a reaction may be slowed down by reversing the above measures.

9. Chemical Formulas and Symbols

The atomic theory (par. 11) enables the composition of various compounds to be expressed in the ratio of their atoms. The present ratios were established in December 1961, using carbon^{12} instead of oxygen as a standard (see table I.) Carbon^{12} was given the arbitrary value of 12, which is referred to as an atomic weight. All other elements were assigned atomic weights relative to carbon^{12}. Some of these are listed in table I, paragraph 12. Each of the elements is also designated by a symbol as shown in table I, which is an abbreviation and stands for 1 atom of the element, or for 1 gram mole or 1 pound mole of the element. Whether for an element or a compound, 1 gram mole of a substance is the number of grams of that substance which equals its atomic weight. Also, 1 pound mole of a substance is the number of pounds of that substance which equals its atomic weight. For example, the symbol for carbon is C, which not only designates 1 atom of carbon, but also from its atomic weight may designate 12 grams or pounds of carbon, depending on the context. Similarly, the formula for water (H_2O) designates that water is formed from 2 atoms of hydrogen and 1 atom of oxygen and that similarly it is formed by 2×1.008 grams of hydrogen and 15.999 grams of oxygen.

10. Chemical Equations

The use of formulas is indispensable in representing the relative weights of the substances used and produced in a chemical reaction. The correct formulas for the reactants are placed to the left of an equal or arrow sign in an equation, while the correct formulas for the products are placed to the right. Then the equation must be balanced; that is to say, each formula must be multiplied by a number which will give as many atoms of an element on one side of the equation as there are on the other side. This is in accord with the law of conservation of matter. Thus the equation for the oxidation of hydrogen to form water is:

$$2H_2 + O_2 \rightarrow 2H_2O$$

In this equation hydrogen and oxygen are represented by H_2 and O_2 and not by H and O because analysis has determined that these elements have 2 atoms within their molecules.

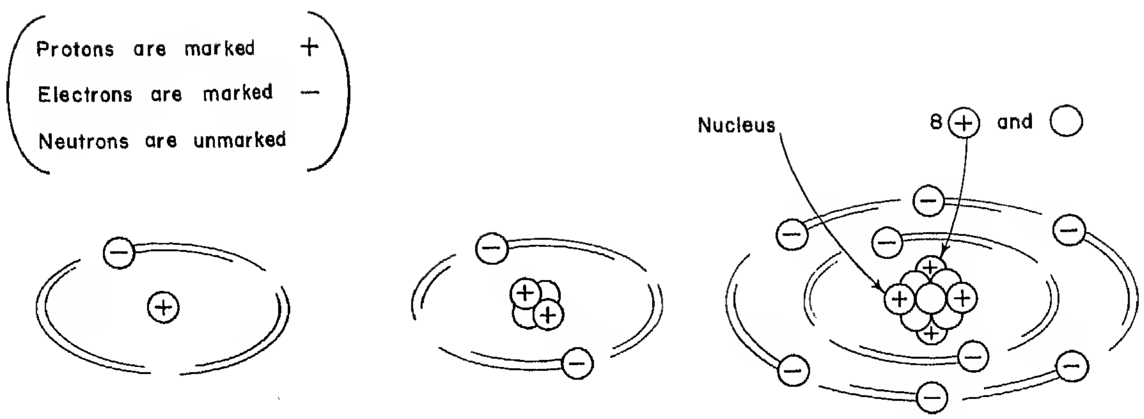
11. Matter

Matter is anything that makes up a physical object; it occupies space and has weight. Under the atomic theory, matter is considered to be made up of units called atoms and molecules.

a. Atoms.

(1) The atom is the smallest unit of mass which possesses all the properties of a given chemical element.

(2) Atoms are made up of three kinds of still smaller particles, two of which have electric charges (fig. 1). The *electron* is the tiniest of these particles; it has a definite charge that is designated as negative. The *proton* is 1,836 times as heavy as the electron. Although its charge is exactly the same as that of the electron in amount, it produces opposite effects and is therefore termed positive. The *neutron* is about as heavy as the proton and has no charge.



	Hydrogen	Helium	Oxygen
Atomic number	1	2	8 (protons)
Mass number	1	4	16 (nucleons)
Atomic weight	1.008	4.003	15.999

Figure 1. Structure of simple atoms.

(3) The atom consists of a nucleus of protons and neutrons (collectively called *nucleons*) around which the electrons whirl like planets around the sun (fig. 1). The nucleons are held together in a compact cluster and a tremendous force is required to break them apart. When the atom is in an electrically uncharged or "neutral" state, the number of orbital electrons equals the number of protons in the nucleus, so that the negative and positive charges just balance each other.

(4) The simplest atom is hydrogen for it has only a single proton nucleus and one electron whirling around it. The more complex atoms have more and more protons and neutrons in the nucleus, together with a corresponding increase of electrons. These electrons are whirling about the nucleus in definite paths called orbits, each orbit having room for only a definite number of electrons. A definite number of orbits makes up a larger unit of electrons called a shell. There is a limit to the total number of electrons that can be in each shell. For all atoms, only 2 electrons can be accommodated in the first shell, 8 in the second shell, 18 in the third, 32 in the fourth, 50 in the fifth and so on. By increasing the size of the nucleus and adding electrons to the outer shells, all the elements can be outlined and constructed.

(5) Two numbers are used in describing atoms (fig. 1). The number of protons in the nucleus (which is equal to the number of orbital electrons in a neutral atom) is called the *atomic number*. It determines the electrical charge of the atom and its chemical properties. The *mass number* of the atom corresponds to the total number of its nucleons. Figure 1 shows the atomic structures of hydrogen, helium, and oxygen. For nuclear reactions, they are frequently symbolized as $_1H^1$, $_2HE^4$, and $_8O^{16}$, respectively. The subscript indicates the atomic number, and the superscript the mass number. All atoms of a given element have the same atomic number.

(6) An element can have a few different mass numbers. These different atoms are called *isotopes* of the element. The average weight of any element's isotopes as they occur in nature is called the element's atomic weight (par. 9).

(7) In the study of gases, it will be seen that certain elements are almost chemically inert; for example, helium, neon, argon, and krypton. Examination of their atomic structures shows that such stability can be related to the composition and symmetry associated with the electron shells. Although the number of shells differs in these elements, the shells are all completely filled. For example, helium has the first shell complete and neon has the first two shells complete.

b. Molecules.

(1) When elements combine to form compounds, it is the individual atoms of the elements that undergo change. In some, but by no means all, cases, it is proper to refer to the particles so formed as molecules. In general, a molecule is the smallest portion or unit of a substance that retains the chemical identity of the mass of substance. The typical molecules are those of hydrogen, water, and oxygen.

Two hydrogen atoms ($H + H$) = one hydrogen molecule (H_2)

Two oxygen atoms ($O + O$) = one oxygen molecule (O_2)

Two hydrogen molecules ($2H_2$) +one oxygen molecule (O_2) = two water molecules ($2H_2O$).

The chemical formation of the hydrogen molecule is shown by two different notations in figure 2. They illustrate the shared electrons (covalent bonding). In chemical reactions of this type, a pair of electrons is shared equally by both atoms, giving a stable molecule (fig. 2).

(2) Also, there are the ionic compounds which are formed by exchanging electrons (ionic bond). The most common example is table salt (NaCl). The sodium atom (Na) transfers one of its electrons to a chlorine atom (Cl). This creates a positively charged atom ion due to the loss of the electron, and a negatively charged chlorine ion due to the gain of an electron. This process can be illustrated by the following equation:

$$Na + Cl \rightarrow Na^{+} + Cl^{-}$$

Two oppositely charged ions of sodium and chlorine have an electrostatic attraction for each other and form a sodium chloride salt. These ions tend to affix themselves in an orderly arrangement called a crystal lattice (fig. 3) in which one sodium atom is surrounded by several chlorine ions and vice versa. The term "molecule" is best not used when referring to ionic compounds because the atoms in an ionic crystal lattice have had a complete electron transfer and are held in place by ionic bonds, while the atoms in a molecule share electrons with each other and are bound by covalent bonds.

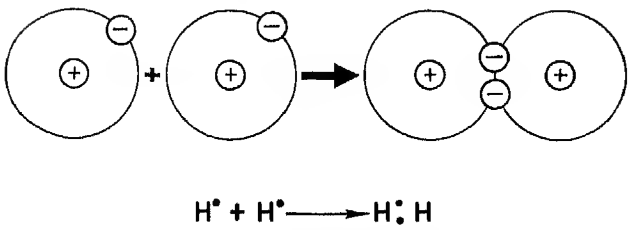


Figure 2. Hydrogen molecule.

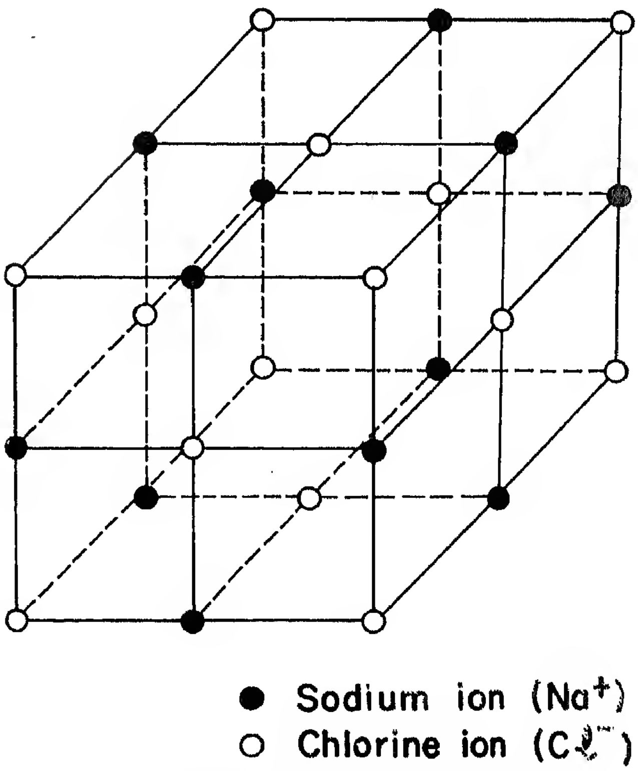


Figure 3. Crystal lattice, sodium chloride (NaCl).

12. Elements, Compounds and Mixtures

a. Elements. An element may be defined as any form of matter which cannot be decomposed or formed by chemical methods. Thus, substances such as oxygen, nitrogen, and hydrogen are elements whereas substances such as salt or water are compounds. It is estimated that about 99 percent of the earth's crust is made up of only 12 of the basic elements known to exist in nature. Table I lists the elements used in the gas-generation units discussed in this manual.

b. Compounds. While there are slightly over 100 elements, 92 of which occur naturally, there is a great variety of chemical compounds or combinations of elements. Thus water is a chemical combination of the atoms of hydrogen and oxygen. Common salt is a combination of the sodium and chlorine. In combinations of this type, the compound formed always contains a definite proportionate weight of the elements involved. For example, the chemical compound of water is expressed in formula by the symbols H_2O indicating that one atom of oxygen has united with two atoms of hydrogen. Referring to table I listing the atomic weights of materials, the atomic weight of oxygen is found to be 15.999 and the atomic weight of hydrogen is 1.008. The total weight of one molecule of water then will be 15.999 plus 2(1.008) or 18.015. The percentage of each element in the compound may be found therefore by dividing the total weight of the compound into the weight of the element desired and multiplying by 100. Thus in water we may find the percentage of oxygen and hydrogen present in the compound as follows:

$$\frac{15.999 \text{ (atomic weight of oxygen)}}{18.015 \text{ (atomic weight of total)}} \times 100 =$$

88.8 percent oxygen

for Hydrogen:

$$\frac{2\ (1.008)}{18.015} \times 100 = 11.2 \text{ percent hydrogn.}$$

Similarly in table salt having the chemical formula NaCl which was shown in figure 3, the percentage of chlorine (60.7 percent) and sodium (39.3 percent) may be computed in like manner. A compound will always have properties different from those of the elements of which it is constituted. Under normal conditions, water is a liquid compound is made up of gaseous elements, whereas ordinary white table salt is composed of a greenish-yellow gas (chlorine) and a silvery-white metal (sodium). Compounds, therefore, are combinations of elements combined in definite proportions by weight to form new substances having their own characteristic properties.

Table I. Atomic Weights of Materials Common to Gas-Generating Processes

Name	Symbol	Atomic weight	Atomic No.
Argon	Ar	39.948	18
Calcium	Ca	40.080	20
Carbon[12]	C	12.000 *	6
Chlorine	Cl	35.453	17
Helium	He	4.003	2
Hydrogen	H	1.008	1
Iron	Fe	55.850	26
Krypton	Kr	83.800	36
Manganese	Mn	54.940	25
Neon	Ne	20.183	10
Nitrogen	N	14.007	7
Oxygen	O	15.999	8
Potassium	K	39.102	19
Sodium	Na	22.997	11
Sulfur	S	32.064	16
Tungsten	W	183.850	74
Xenon	Xe	131.300	54

* Carbon[12], instead of oxygen, is standard of comparison; see paragraph 9. Adopted by the International Union of Pure and Applied Chemistry in 1961.

c. A mixture differs from a compound in that the individual substances are not chemically combined with any other substance present in the mixture. A mixture then is a mechanical combination of two or more compounds in any proportion without the loss of any properties of the individual substances. Atmospheric air is probably the best example of a mixture and consists of oxygen, nitrogen, water vapor, argon, and other gases.

13. States of Matter

From a casual examination of the surroundings, it is evident that matter exists in three states—a solid, a liquid, or a gas. For example, water may exist as a solid (ice), a liquid (water), or a gas (steam). A gas has no definite size and shape but merely a definite mass. It is composed of molecules or single atoms which are relatively far apart and free to move because the attractive or binding forces between them are very weak. A liquid has definite mass and size, but no form. It too is composed of molecules or single atoms, which are more closely packed together, but are still mobile be-

cause their attractive forces are weak. A solid has definite mass, size, and shape. The molecules are tightly knit together and resist deformation because of their strong attraction for one another. Liquids and gases both are sometimes called fluids because of their ability to flow. In this case they are distinguished from each other by their relative compressibility; liquids are only slightly compressible, but gases are highly compressible. The state of a substance, however, can be changed by an increase or decrease in the temperature or pressure. For example, a substance such as carbon dioxide can change from its normal gaseous state into a liquid or even a solid (dry ice) by an increase in pressure and sufficient cooling. Furthermore, some substances can change directly from a gas to a solid or exist only as a liquid or gas. The various changes from one state to another have certain designations and these terms will be used in the ensuing gas-generation discussion. These terms are:

a. Solid to liquid is melting or fusion.

b. Liquid to solid is freezing or solidification.

c. Liquid to gas is evaporation, vaporization, or boiling.

d. Gas to liquid is condensation.

e. Solid to gas is sublimation.

f. Gas to solid is desublimation.

Throughout all these changes, however, it must be remembered that although matter can be made to change its state, it cannot be created or destroyed. Although under very special conditions, as described by Einstein and others, mass and energy have been shown to be interchangeable ($E=mc^2$), this relation will not significantly affect the principles covered in this manual and can be disregarded.

14. Energy

Energy is the ability of a body to do work. It exists fundamentally in two classes—kinetic energy and potential energy.

a. Kinetic. Kinetic energy is the energy possessed by a body by virtue of its motion. For example, a moving train, a rotating wheel, or a bullet in flight, all have kinetic energy.

b. Potential. Potential energy is sometimes called stored energy and is the energy in a body because of its position or its chemical or physical state. For example, a weight suspended in air, fuel oil or gasoline in gas-generating plants, or gases under compression in units or cylinders, all possess potential energy.

15. Forms of Energy

There are several forms of energy—mechanical, electrical, light, thermal, and chemical. In this manual the last two are of principal concern, though many examples of electrical and mechanical energy can also be found. Like matter, however, energy cannot be created or destroyed but can be converted from one type to another. The majority of the chemical reactions used in gas generation, as well as the design of equipment, have taken advantage of this natural law of energy conversion.

16. Heat

Heat is a form of energy. When heat is supplied to a body, it increases the temperature of that body. The energy supplied as heat is said to increase the *internal energy* of the body because the energy appears to be given to the molecules of that body. Since molecules are in incessant motion, they are known to have kinetic energy. Some of them have potential energy. This is true for molecules of a solid or liquid that has been expanded by heating; work must have been done to separate them. Gas molecules have little potential energy because they are relatively far apart and consequently have slight attraction for one another. Heating, therefore, has a direct effect upon the internal energy of a body, whether kinetic or potential. It is the result of the motion of the molecules and atoms. Heat applied to water causes the molecules to vibrate faster and faster and the distance between them becomes greater and greater until the water changes to steam. Removal of the heat accomplishes a reverse action. When a vessel containing gas is heated, the gas molecules striking the heated sides of the vessel in their incessant vibration rebound with greater speeds, strike other molecules, and in this way the entire gas is heated. Heat, then, is transferred from one body to another, for example, from the vessel to the gas, as described above, or from a hot radiator to the air of a room. To determine accurately the amount of heat added in making the above conversions, or in other reactions, some relative units of heat measure and scales of temperature have been established.

17. Types of Heat

a. Sensible Heat. To understand the types of heat, it is necessary to remember that matter exists in three states—solid, liquid, or gas. In any one of these states its temperature may be varied. For example, water is frequently seen in all three states, that is, ice, water, or steam. Water at atmospheric pressure exists in solid states at temperatures from 0°C. (32°F.) down, in a liquid state from 0°C. (32°F.) to 100C. (212°F.) and in a gaseous state from 100°C. (212°F.) up. Consider water in the liquid state. If a burner is placed under a pan of water, the water's temperature will rise. As the temperature rises, the addition of heat can be felt, or *sensed,* which is the origin of the term *sensible heat.* Going in the opposite direction, if the pan of water is placed in a refrigerator, the temperature will begin to fall. This is an example of the removal of sensible heat. Therefore, sensible heat is the heat that causes a change of temperature.

b. Latent Heat. Latent heat is the heat that changes the state of a substance, rather than its temperature. To understand this, after a pan of water is set over a burner, the water's temperature rises until it reaches 100°C. (212°F.). At this point, the water begins to change to steam, yet the water's temperature ceases to rise.

18. Heat Measure

One term used in heat measurement is specific heat. Other terms may be defined as follows:

a. One calorie equals the quantity of heat necessary to raise the temperature of 1 gram of water 1° centigrade.

b. One Btu equals the quantity of heat necessary to raise the temperature of 1 pound of water 1° Fahrenheit.

c. Numerically, specific heat is equal to the calories required to raise the temperature of 1 gram of the substance 1° centigrade or the Btu's required to raise 1 pound of the substance 1° Fahrenheit.

19. Temperature

Four temperature scales are in common use. For the *Fahrenheit* and *centigrade,* temperatures are taken as the melting point of ice and the boiling point of water. The *Fahrenheit* scale is common to the English system. The *centigrade* scale is common to the metric system of measurement. The other two scales show *absolute temperatures;* their values are reckoned from a temperature that is considered theoretically to be the lowest possible. They are used mostly in thermodynamics. One is based on centigrade divisions and is called the *Kelvin* scale; the other is based on Fahrenheit divisions and is called the *Rankine* scale. All scales are shown in figure 4 and table XI for comparison. Temperature can be converted from the centigrade to the Fahrenheit scales, or vice versa, by substituting in the following formulas:

$$F = 9/5\ C + 32$$
$$C = 5/9\ (F-32)$$

20. Change of State

a. Heat of Fusion. The heat of fusion of a substance is the number of calories required to melt 1 gram of the substance without changing its temperature. At standard atmospheric pressure, ice melts at 0°C. (32°F.). Under these conditions, 1 gram of ice in melting absorbs 80 calories *from* its surroundings, and conversely 1 gram of water in freezing dissipates 80 calories *to* its surroundings. This means that under standard pressure the heat of fusion of ice

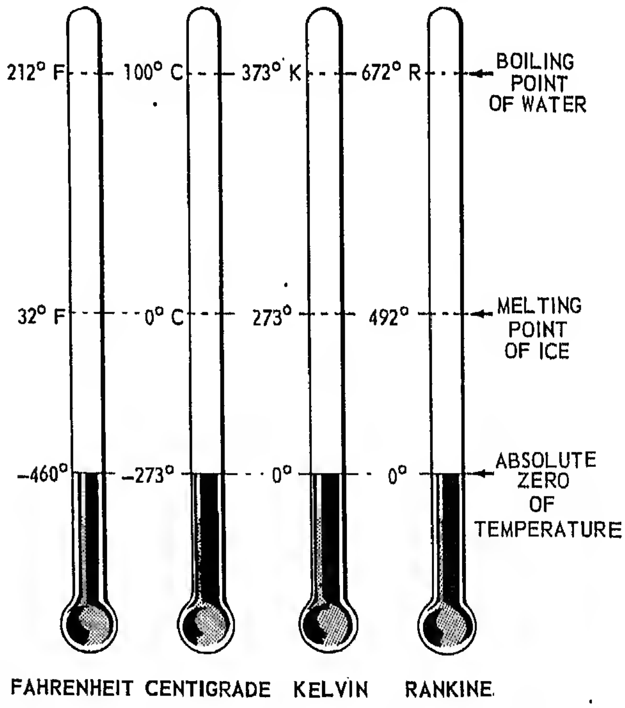


Figure 4. Comparison of thermometer scales.

is 80 calories per gram. The heat of fusion of ice is also expressed as 144 Btu's per pound.

b. Vaporization. The heat of vaporization of ı substance is the number of calories required :o vaporize 1 gram of the substance without :hanging its temperature. The same amount of ıeat is dissipated when 1 gram of the substance :ondenses. While a liquid is evaporating into ı closed space, the molecules of vapor fly off in :andom directions and collide with and rebound :rom one another and from the walls of the con- :aining vessel. Some of them eventually return :o the surface of the liquid with sufficient speed :o reenter the liquid and recondense. After :nough molecules have collected in the space ıbove the liquid, their wanderings bring them)ack to the surface as frequently as other mole- :ules escape. Therefore, there is a balance be- :ween evaporation and recondensation. This naintains a constant number of molecules in :he closed space above the liquid at any given :ime, and the accompanying bombardment on :he walls of the vessel sets up a definite con- stant pressure called the vapor pressure. Vapor)ressure then depends on the temperature and ıature of the liquid (being different for differ- :nt pure liquids at any given temperature). The ɪuantity of a liquid is a factor only in that there nust be enough liquid present to prevent all of t from evaporating before equilibrium is 'eached.

c. Specific Heat. Like the specific heat of .ny substance, the determination of the specific ıeat of a gas is also numerically equal to the .mount of heat necessary to raise the tempera- ure of a unit mass 1°. However, the specific ıeat of a gas is not a single value, but may be wo or more values, depending upon the con- traints that are placed on the gas while it is ›eing heated. For example, to raise 1 pound f gas 1°F., more heat would be required if the ;as were kept at constant pressure rather than .t constant volume. This is evident for when he gas is held at constant pressure, the gas is ree to expand and do work and the energy ıeeded to do this work must come from the heat upplied; whereas, at constant volume it cannot xpand. The increase of internal energy is the ame in each process because in each one the emperature rise is the same. Consequently, he specific heat of a gas at constant pressure exceeds its specific heat at constant volume. Since both pressure and volume can be varied, the most important values for the specific heat of gases both under constant pressure (Cp) and under constant volume (Cv) are listed in table II.

Table II. Specific Heat of Gases at Standard Conditions
(Specific heats of gases vary with temperature.)

Gas	Cp Cal/gm/C°	Cv Cal/gm/C°
Oxygen	0.217	0.155
Nitrogen	0.247	0.176
Hydrogen	3.429	2.435
Carbon dioxide	0.204	0.160
Acetylene	0.330	0.274

Cp = Specific heat at constant pressure.
Cv = Specific heat at constant volume.

21. Gas Laws

All gases conform to certain physical principles regarding temperature, pressure, and volume. First, it is known that all gases exert pressure. This pressure is expressed as absolute pressure. The absolute pressure of any gas can be obtained by oberving the gage pressure and adding atmospheric pressure (14.7 psia) to it. (The absolute pressure of a gas will always

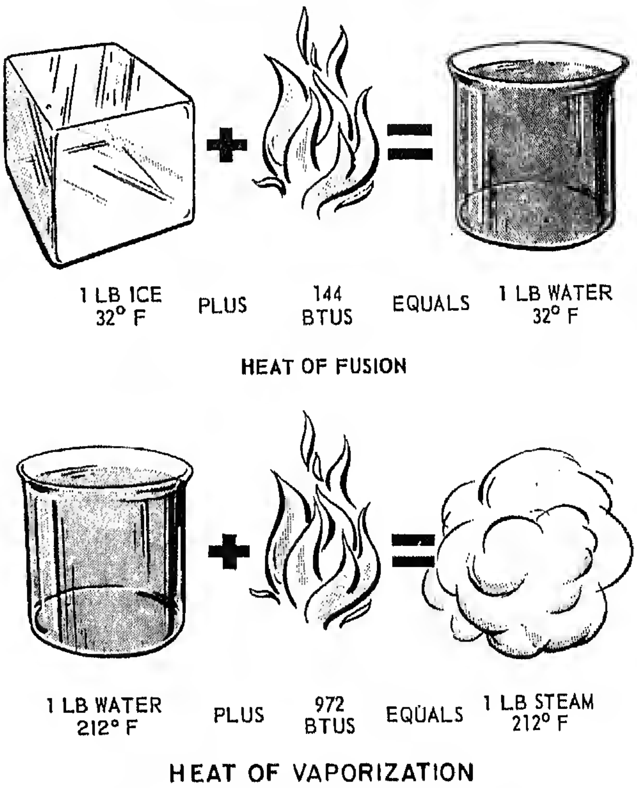


Figure 5. Ice-water-steam analogy.

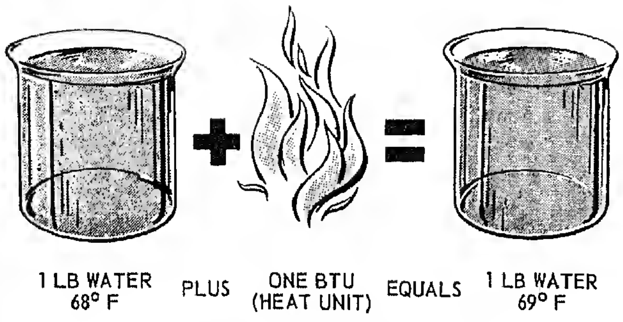


Figure 6. Determination of specific heat of water.

be designated by the term *psia,* whereas the gage pressure is shown as *psig* after the reading.) Second, all gases occupy space and therefore must have volume; and third, temperature affects the gas. The gas laws correlate these three variables with the effect they have on the condition of an ideal gas. No real gas actually exhibits the properties of an ideal gas, but the gas laws can usually be applied to all gases without involving any great error. Exceptions occur at high pressures, low temperatures, or if a phenomenon such as the Joule-Thompson effect occurs (par. 36*a*).

22. Boyle's Law

a. Principle. Boyle's Law shows a simple relation between the pressure of a gas and its volume, and states that the volume of a confined body of gas varies inversely to the absolute pressure, if the temperature remains constant, that is, doubling the pressure upon a body of gas halves its volume. Boyle used a J-shaped tube called a manometer for his study (fig. 7). First, he poured enough mercury into the tube so that the mercury stood at the same level (L) in both arms of the tube (fig. 7). The air (LC) trapped in the closed end was therefore under the same pressure as that in the open end, which was 29 inches of mercury in one experiment. Assuming that the tube was uniform, the volume of the closed air was directly proportional to the length (LC). Boyle then added mercury until the mercury levels rose to M in the closed (shorter) arm and to N in the open (longer) arm, making MC just one-half of LC. The added pressure had reduced the volume of the air to one-half its former volume. Measuring the excess height (MN) of the mercury volume in the open (longer) arm of the tube, he observed that the mercury was 29 inches higher than in the closed (shorter) arm of the tube. Therefore, doubling the pressure on the air had halved its volume, or pressure and volume are inversely proportional to one another. From this Boyle concluded that pressure times volume of an enclosed gas is constant if the temperature and mass are constant, or the density of an enclosed gas at constant temperature is directly proportional to the pressure to which it is subjected. As an algebraic formula, it reads:

$$V_1 P_1 = V_2 P_2$$

or

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

Where V_1 and P_1 signify the original volume and pressure, and V_2 and P_2 signify the new volume of the gas and the new pressure which causes it. This equation is true, providing the temperature has remained the same.

b. Illustrative Problem. Four cubic feet of oxygen are under a pressure of 100 psig. The oxygen is allowed to expand to a volume of 6

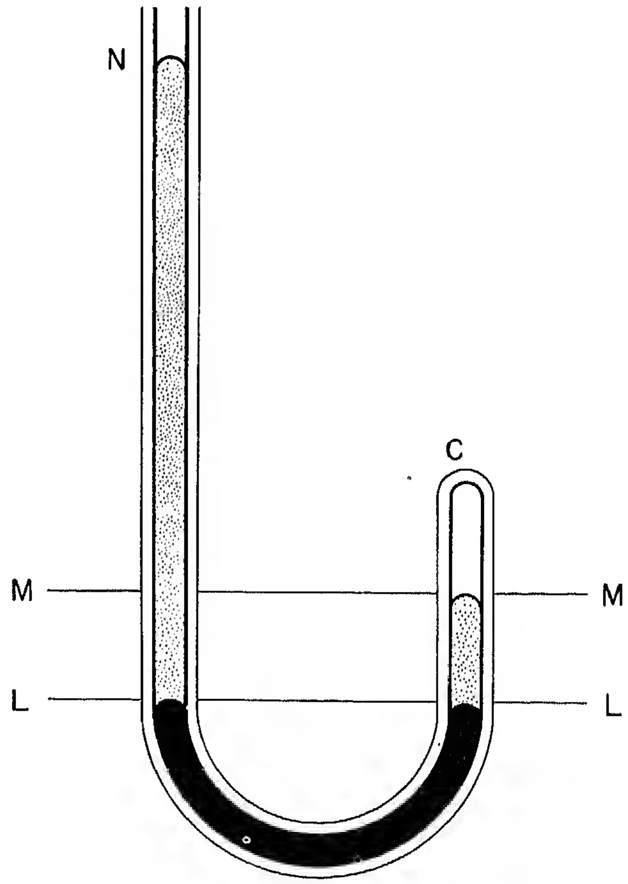


Figure 7. Boyle's pressure tube.

cubic feet. What is the new gage pressure– (Do not forget to convert gage pressure to absolute pressure by adding 14.7 psia.).

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}, \text{ or } V_1 P_1 = V_2 P_2$$

$$4 \times (100 + 14.7) = 6 \times P_2$$

$$P_2 = \frac{4 \times 144.7}{6}$$

$$P_2 = 76.5 \text{ psia.}$$

Converting absolute to gage pressure,
$76.5 - 14.7 = 61.8$ psig.

23. Charles' Law

a. Principle. A mass of gas can be kept at a constant pressure by enclosing it in a cylinder equipped with a freely moving piston (fig. 8), for the slightest change of pressure causes the piston to move in or out, keeping the pressure inside the cylinder constant at the value existing on the outside. When a gas is heated under these conditions, it is found that volume varies in direct proportion to the absolute temperature. This relation was discovered by the French physicist, Jacques A. C. Charles. Expressed as an equation for any two conditions of volume and temperature, Charles' law reads:

$\frac{V_2}{V_1}=\frac{T_1}{T_2}$ at constant pressure, where V_1 and V_2 are the volumes of the gas at temperatures T_1 and T_2, respectively. This is shown in the curve in figure 8.

b. Illustrative Problem. A cylinder with a freely moving piston contains 50 liters of a gas at 27°C. If the temperature is raised to 127°C., what will be the new volume if the pressure has remained constant? (Convert temperature to *absolute* temperature.)

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

$$\frac{50 \text{ liters}}{V_2} = \frac{27°\text{C.} + 273}{127°\text{C.} + 273}$$

$$\frac{50 \text{ liters}}{V_2} = \frac{300°\text{A}}{400°\text{A}} = \frac{3}{4} = .75$$

$$V_2 = \frac{50 \text{ liters}}{.75}$$

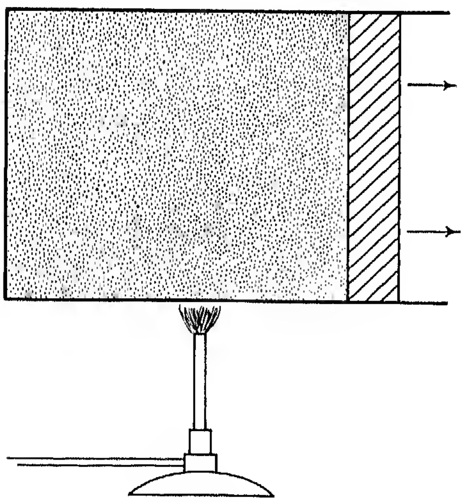
$$V_2 = 66.6 \text{ liters}$$

24. The General Gas Equation

The general gas equation (or law) shows the relation betwen the pressure, volume, and temperature of a fixed mass of an ideal gas when none of these quantities is kept constant (fig. 9). It is expressed as follows:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

This relationship holds regardless of variation in pressure, temperature, or volume. Whether for ideal or real gases, the equation shows that any units of volume, absolute pressure, and absolute temperature may be used as long as the same units are used on both sides of the equation.



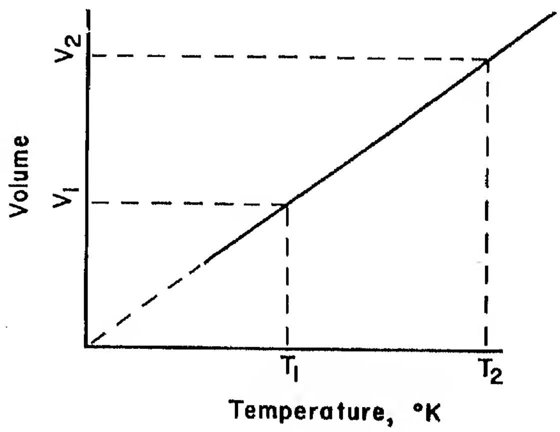


Figure 8. Volume of gas heated at constant pressure increases with temperature.

Table III. *Data on Air, Its Components, and Inert Elements*

Substance	Critical temperature, °C.	Critical[2] pressure, in atm	Critical[2] density, g/cc	Melting point, °C. at 1 atm	Boiling point, °C. at 1 atm	Percentage[5] by volume at sea level	Molecular weight	Specific gravity of liquid at boiling point	Atomic weight
Oxygen	−118.8	49.7	0.430	−218.40	−183.00	20.99	32.0	1.143	15.999
Nitrogen	−147.1	33.5	0.311	−209.86	−195.80	78.03	28.0	0.808	14.007
Carbon-dioxide[1]	31.1	73.0	0.4600[3] (plait point)	−56.60[4] (5.2atm)	−78.50	0.03	44.0	---------	---------
Hydrogen	−239.0	12.8	0.031	−259.18	−252.80	0.01	2.016	---------	1.008
Air	−140.7	37.2	0.350	---------	---------	100.00	---------	---------	---------
Helium	−267.9	2.26	0.069	−272.20	−268.90	0.0004	4.0	---------	4.003
Neon	−228.7	25.9	0.484	−248.67	−245.90	0.00123	20.18	---------	20.183
Argon	−122.0	48.0	0.531	−189.20	−185.70	0.940	39.94	---------	39.948
Krypton	−63.0	49.0	0.780	−157.00	−153.21	0.00005	83.7	---------	83.800
Xenon	16.6	58.2	1.155	−112.00	−107.10	0.000005	131.3	---------	131.300

Definitions

Boiling point—The temperature at which the vapor pressure of a liquid equals the local pressure. Normally, this is atmospheric pressure (14.7 psia).

Critical temperature—That temperature above which a gas cannot be liquefied regardless of pressure.

Critical pressure—Pressure at which a substance exists as a gas in equilibrium with the liquid at the critical temperature.

Critical density—Density of a substance at its critical pressure.

Melting point—Temperature at which the solid and liquid states of a substance are in equilibrium.

* U.S. Pat. Office.

1 Sublimation point of carbon dioxide at 1 atm equals —78.50°C.

2 atm = standard atmosphere; g/cc = grams per cubic centimeter; mm = millimeter.

3 Plait point is point at which carbon dioxide can exist as a solid, liquid or gas.

4 Melting point of carbon dioxide at 73 atms equals —56°C.

5 Percentage by volume at sea level is based on 760 mm pressure.

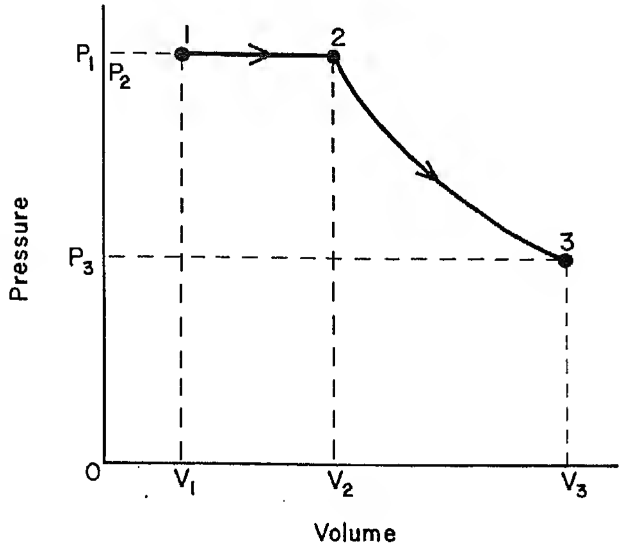


Figure 9. Pressure-volume diagram for gas expansion at constant pressure (1–2), and at constant temperature (2–3).

Section III. LIQUEFACTION AND SEPARATION OF AIR

25. Introduction

Air is a colorless, odorless, and tasteless mixture of gases. It is compressible and elastic and varies in composition with evaluation and humidity. In addition to its major components (oxygen and nitrogen), air contains carbon dioxide, water vapor, and minor quantities of inert gases. For further data, see table III. In the liquid state, it can be separated into its various components by a process called fractional distillation. The term "fractional" is applied to the process of distillation when a mixture is separated through differences in the boiling points of its components.

26. Components of Air

a. Oxygen.

(1) The chemical formula for oxygen is O_2. Though it is an excellent supporter of combustion it is nonflammable. Oxygen is slightly heavier than air and slightly soluble in water. As a liquid, oxygen is deep blue, and somewhat heavier than water. It boils at —182.7°C. (—296.8 F.) and forms a solid at —218°C. (—360.4 F.) at atmospheric pressure.

(2) Oxygen is the most abundant and widely distributed element on earth. About 21 percent by volume, or 23 percent by weight, of our normal atmosphere is oxygen. About 46.5 percent of the weight of the earth's crust is estimated to be oxygen because 50 percent of the weight of silicates and some other solid minerals is oxygen. About 85 percent of the weight of the ocean is oxygen.

(3) At normal room temperature, gaseou oxygen as a component of air is onl; mildly reactive, but at higher tempera tures it combines rapidly with most elements and many compounds.

(4) Commercially, oxygen is obtained by the fractional distillation of liquid air. The liquid remaining after other atmospheric gases have boiled away from liquid air is *liquid oxygen.* Oxygen can also be generated by the electrolysis of water.

(5) The formation of oxides by combination of oxygen with another substance is known as oxidation. Heat energy is produced whenever a substance is oxidized. If the reaction is slow and only heat energy is given off, the process is called *slow oxidation.* If oxygen combines with the other substance so rapidly that light energy as well as heat is evolved, the process is called *combustion.* The flame produced by combustion consists of burning gases vaporized from the combustible substance by the heat of the reaction. Spontaneous combustion is likely to occur in combustible material which is a poor conductor of heat if stored in still air. Under those conditions, the oxygen in the air slowly begins to oxidize the combustible material, which generates heat. If the heat is not conducted away, but accumulates around the material, eventually the temperature of the combustible material is raised to its kindling temperature and active combustion occurs.

b. Nitrogen.

(1) The atmosphere is the only important source of free nitrogen. However, since the atmosphere consists of about 78 percent nitrogen by volume and 75.5 percent by weight, the supply is abundant.

(2) The chemical formula for nitrogen is N_2. It also is a colorless, odorless, and tasteless gas. However, it is not combustible and does not support combustion. Nitrogen is slightly lighter than air and retards the combustion or oxidation of other elements by being a diluting agent. As a liquid it boils at —195.6°C. (—320.2°F.) under atmospheric pressure.

(3) The outstanding characteristic of nitrogen is its high degree of stability. While it does not readily combine with other elements, it does combine with some to form nitrides when temperatures are high enough to provide the necessary heat energy.

(4) Commercially, practically all nitrogen is obtained from the fractional distillation of liquid air.

c. Carbon Dioxide.

(1) In addition to forming about 0.03 percent by volume of the atmosphere, carbon dioxide is dissolved in all natural waters forming carbonic acid (which attacks copper or tin) and is present in a variety of carbonate minerals and rocks, the most abundant of which is limestone.

(2) Carbon dioxide (CO_2) is a chemical compound of carbon and oxygen in the ratio of 1 to 2. It is heavy, inert, colorless, and odorless. It varies in its concentration in air and is removed from it by plants which use it as food to sustain growth. It liquefies at about 830 psig at 20°C. (68°F.), and solidifies if the temperature drops to —56°C. (—69°F.) At a pressure below 5.2 atms, the solid passes directly to the gaseous state as its temperature is raised. This phenomenon is known as *sublimation.* In liquid form it is used extensively as a refrigerant, and in solid form (dry ice) as a coolant.

(3) Carbon dioxide is a stable compound which does not burn and does not support combustion. It combines with oxides and hydroxides of the active metals to form carbonates.

d. Hydrogen. Only about 0.01 percent of air is hydrogen. For further information, see paragraph 62.

e. Water. Water (H_2O) is also a chemical compound. It is a colorless, odorless, and tasteless liquid, which boils at 100°C. (212°F.) and freezes at 0°C. (32°F.). Because of the presence of water and carbon dioxide in the atmosphere, all generating plants using fractional distillation of air for oxygen generation must shut down periodically to remove the ice which is inevitably formed in their low-temperature components.

f. Insert Gases. The inert gases found in air—argon (A), neon (Ne), helium (He), xenon (Xe), and krypton (Kr)—are commonly

referred to as rare gases. As a group they are colorless, odorless, and tasteless, and all can be condensed to a liquid or solid if the temperatures are low enough (—100° to —270°C., or —148°F. to —454°F.). As rare gases they exist (with the exception of argon at 0.94 percent) in minute amounts in air. They are chemically inert. Specific uses of these gases are:

(1) Argon is used in filling electric light bulbs and as a gaseous shield for the electric arc in welding certain metals.

(2) Neon serves as a filling for electric light bulbs, particularly glow lamps.

(3) Helium is the lightest of the gaseous elements of the rare group. It is used in heliarc welding. Because of its nonflammable characteristics, it also has replaced hydrogen in lighter-than-air craft. Because it is twice as heavy as hydrogen, it does not diffuse as readily.

(4) Xenon and krypton have no military uses.

27. Liquefaction of Air

Ambient air can be liquefied by refrigerating it under pressure. Refrigeration is the primary requirement. It is a commercial source of both oxygen and nitrogen. Commercial byproducts of the fractional distillation of air are neon, argon, and other atmospheric gases.

a. Process. To liquefy air, it is first filtered and compressed, while at the same time the heat of compression and the condensed water vapor are being removed. Air is then refrigerated by use of heat exchangers and mechanical refrigeration, plus expansion, to a temperature and pressure which will cause it to liquefy. It is then separated and purified through distillation. Cold gases, mainly nitrogen, from this process are recirculated to the heat exchangers to provide refrigeration for the incoming air (fig. 10).

b. Appearance of Liquid Air. Liquid air resembles water in appearance. It is a mixture of nitrogen, oxygen, and a negligible quantity of rare gases. This mixture does not have a constant boiling point; it boils over a range from —194.4°C. (—317.9°F.) to —183.9°C. (—299.0° F.) at which point the liquid mixture has completely returned to gas.

28. Separation of Gaseous Mixtures

a. Principles. Processes for the separation of gaseous mixtures depend upon two basic facts: mixtures of gases under pressure liquefy at low temperatures, and specific gases boil at different temperatures. When a mixture of gases is liquefied by pressure and low temperature (refrigeration), its constituents can then be boiled off one at a time (which is the process of fractional distillation) by raising the temperature of the mixture (fig. 11).

b. Critical Temperatures. Each gas has its critical temperature, that is, the temperature to which it must be reduced before it can be liquefied, regardless of how much pressure is applied. Table III gives this critical data on the components of air.

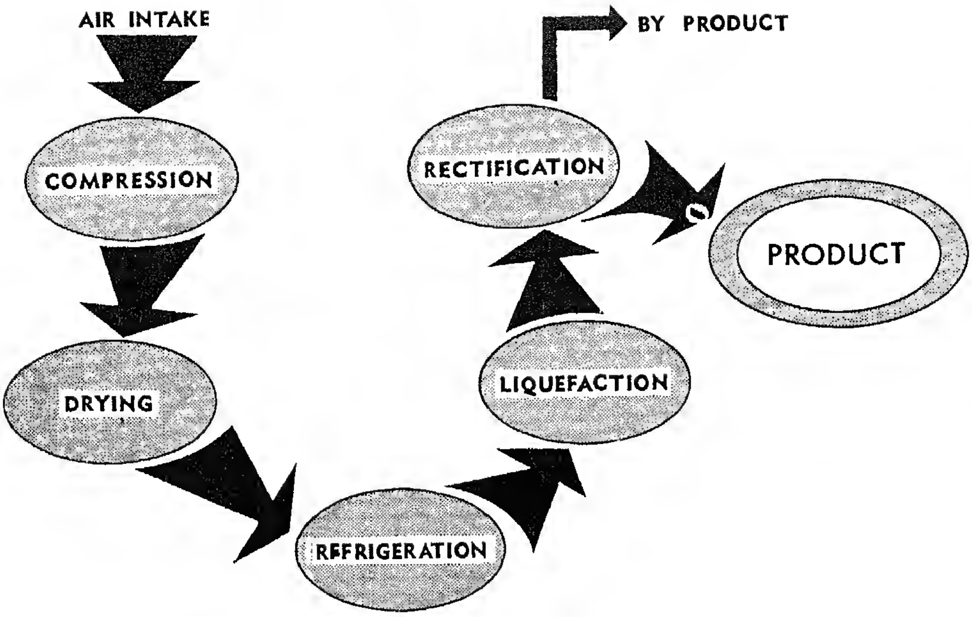


Figure 10. Basic flow diagram, low temperature separation of gases.

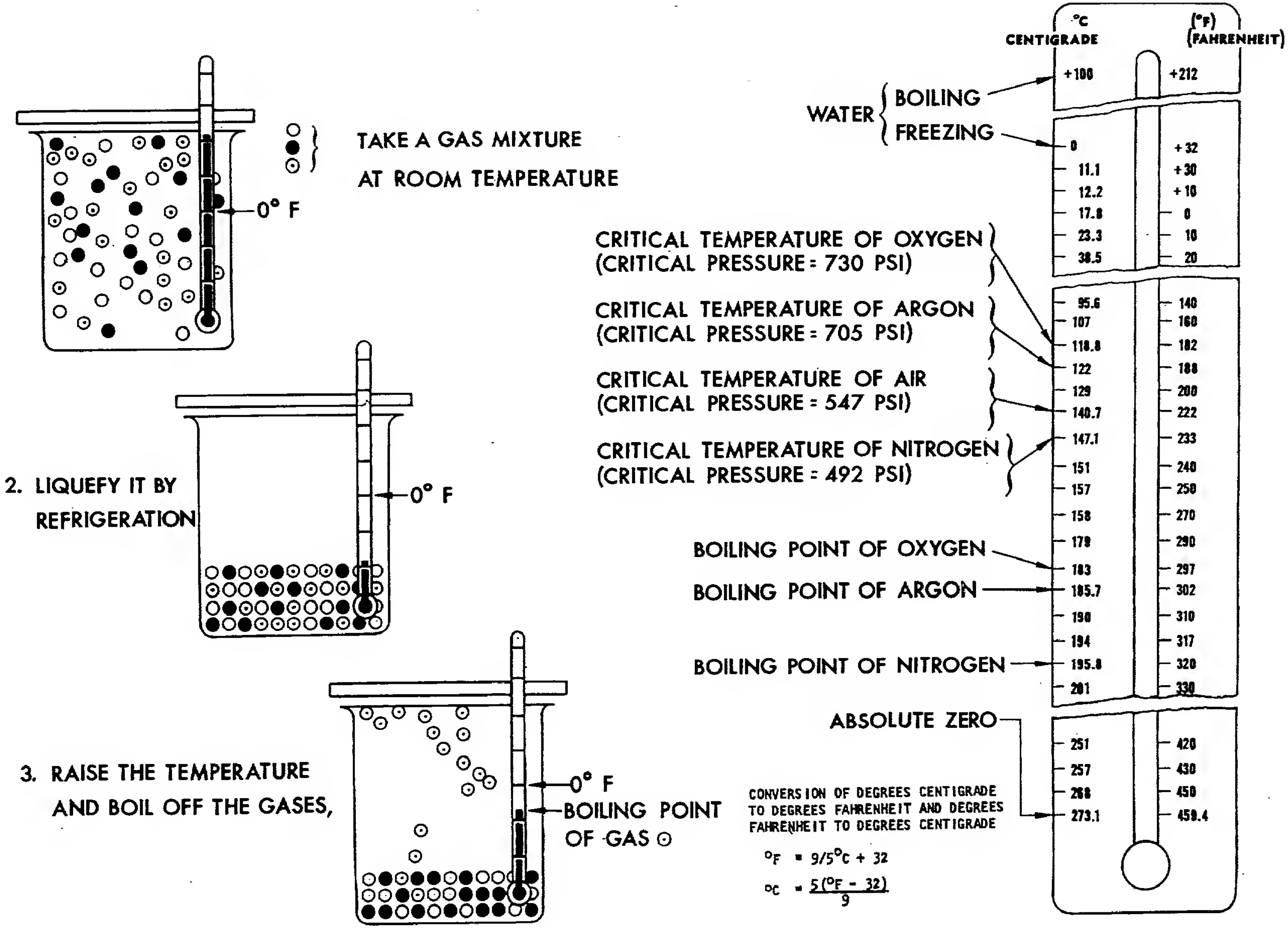


Figure 11. Basic principle of low-temperature separation of gases.

CHAPTER 2

GENERATION OF OXYGEN AND NITROGEN

Section I. INTRODUCTION

29. Content

In the generation of oxygen or nitrogen, each element is processed into liquid form before it is processed into gaseous form. Following a brief discussion of the uses and sources of oxygen and nitrogen, this chapter explains the cooling process, then describes the generation of both the liquid and gaseous forms of oxygen and nitrogen.

30. Uses of Oxygen and Nitrogen

a. Oxygen. Some uses of oxygen are as follows:

(1) For hospital patients suffering from diseases where a breathing aid is necessary. Oxygen of U.S.P. grade (minimum purity 99%) is required for this purpose.

(2) In high-altitude flying. Oxygen of high purity (99.5% minimum) and low moisture content is required to compensate for the lack of oxygen in the rarefied atmosphere and to prevent freezeup of controls and lines at low temperatures.

(3) In the restoration of air volume in submarines.

(4) In oxyacetylene welding and metal cutting. Oxygen of minimum purity of 99.5% is required. Lower purity oxygen will not produce a satisfactory weld.

(5) As an oxidizer for most liquid-propellant missiles.

b. Nitrogen. Some of the chief uses of nitrogen are as follows:

(1) In mechanisms and equipment used by the Army, such as flamethrowers and recoil mechanisms.

(2) As a fertilizer, for example, as a compound, (NH_3 or $CaCN_2$). The process of transforming nitrogen (N_2) from the atmosphere into nitrogen compounds (NH_3 or $CaCN_2$) is termed the *fixation of nitrogen.*

(3) For making nitric acid and explosives.

(4) For bright-annealing steel. In this operation a nitrogen atmosphere is used.

(5) In hardening steel. It is used in combination with many metals to form nitrides (Fe_3N_2).

(6) As the gaseous atmosphere in incandescent lamps to prevent arcing.

(7) As a coolant for missile guidance systems.

(8) For purging missile systems.

(9) As a raw material in the production of ammonia and similar compounds.

31. Sources

a. Oxygen. The discovery of oxygen as an element was made by two chemists, Priestley and Scheele, working independently of each other. Since its discovery, many methods have been perfected for the production of oxygen. The following have the most practical value today:

(1) *Electrolytic method.* The electrolytic method of producing oxygen is generally reserved for production on a laboratory scale. An electric current is passed through water, containing sulfuric acid as a catalyst, causing the water to decompose into its constitu-

ents—oxygen and hydrogen. The oxygen is liberated at the positive pole and the hydrogen at the negative pole.

(2) *Chemical method.* The most convenient laboratory method for the preparation of oxygen is by heating certain chemical compounds until they decompose. Potassium chlorate is most commonly used; it loses all its oxygen when heated above its melting point of 368°C. (694.4°F.) Potassium nitrite is another chemical that may be used.

(3) *Fractional distillation of air.* This is the method currently used by the large commercial gas producers and by the Army for the extraction of oxygen from the air. Therefore, it will be discussed in detail in this chapter. The liquid-air process separates the various gases that constitute air by cooling the air to a temperature at which most of its components will liquefy. The liquid air is then separated by distillation into oxygen, nitrogen, argon, and other components.

b. Nitrogen. Nitrogen was discovered by Rutherford in 1772 and is chiefly produced by the following methods:

(1) *Chemical method.* In this process a chemical compound, such as any of the natural nitrates, is decomposed by a chemical reaction to free the nitrogen from the compound. At present this method is not used by the Army or any of the large commercial gas producers and is not likely to be used in the future.

(2) Fractional distillation of air. This method, previously discussed as a means for producing oxygen, is also used to produce nitrogen. It is the process currently used commercially and by the Army.

Section II. THEORY OF COOLING

32. Critical Temperature

The temperature to which a gas must be reduced before pressure can liquefy it is termed the *critical temperature.* This is defined as that temperature above which it is impossible to liquefy the gas. Correspondingly, the *critical pressure* is defined as that pressure required to liquefy the gas at the critical temperature. Unless a gas is at or below its critical temperature, pressure alone can never produce liquefaction. Table III lists some of the gases and their critical temperatures and pressures. Carbon dioxide, for example, can be liquefied at room temperature if the pressure is high enough, whereas the critical temperatures of oxygen and nitrogen are extremely low. Just how low these temperatures are is difficult to visualize, but if a block of ice were put under a kettle of liquid air, the kettle would boil because the ice is so much warmer than the liquid air. Thus the complexity of oxygen and nitrogen production is increased because extremely low temperatures must be produced before they can be separated.

33. Heat Exchange

The most common of all physical processes used in the manufacture and storage of compressed gases is that of heat exchange or heat flow from a warm to a cold body. Basically this heat may be transferred by one or more of three fundamental methods—conduction, convection, or radiation.

a. Conduction. The temperature of a substance depends on the intensity of the molecular motion as explained in paragraph 16. When heat is transferred by conduction, this molecular motion is passed from molecule to molecule in the direction of decreasing temperature. If one end of an iron bar is placed in a fire, the portion of the bar not in the fire will be heated by conduction.

b. Convection. Heat transfer by convection involves the circulating of a fluid (gas or liquid). The circulating fluid absorbs heat in contacting a warmer surface and loses heat when in contact with a cooler surface. Thus, heat is transferred by convection from the warm to the cold surface. Circulation of the

fluid can be natural, that is, be caused by density variation that accompanies temperature changes in the fluid. An example of this method is a home heating system where the room is heated from a radiator which sets up convection currents. Circulation of the fluid can also be forced, such as by means of a pump or fan.

c. Radiation. Radiation is the method of transferring heat from one mass to another by means of high frequency waves. When these high frequency, heat-energy waves strike or travel through material, they give up energy. This energy is absorbed by the material and raises its temperature. An everyday example of this method of heat transfer is that of the sun heating and warming the earth.

34. Heat Exchanger

The unit which is used to transfer heat from one body to another is called a heat exchanger or an interchanger. It is commonly a steel vessel used to heat or cool a gas or liquid. The most common type of interchanger is the shell-and-tube exchanger which consists of several tubes welded inside a shell. The tubes are fed through a common header (fig. 12). Side baffles are usually provided on the shell so the gas or liquid to be cooled or heated has the maximum amount of exposure with all tubes. Usually the hot liquid or gas flows through the shell and the cooler gas or liquid flows through the tubes. The flow of fluids will geneally be countercurrent to each other. However, this is not a rigid rule.

a. One-Pass Exchanger. Figure 13 shows an example of a one- or single-pass exchanger of the tube and shell type. It gets its name "one-pass" from the fact that the gas or liquid in the shell side (from B to D) comes in contact with the gas or liquid in the tube side (from A to C) only once. Baffles are provided which enable the substance on the shell side to contact the entire tube area.

b. Multipass Exchanger. A multipass exchanger differs from the single pass exchanger in that the substance on the shell side comes in contact with the tube side more than once. This is done by placing a partition plate in the header. As shown in figure 14, if one plate is put in the header the gas or liquid on the shell side passes through the length of the exchanger twice and is thus called a two-pass exchanger. Many factors, such as heating or cooling effect desired, economic considerations, thermodynamic principles, and properties of the fluids involved determine the number of passes an exchanger should have.

35. Refrigeration Process

To obtain the low temperatures necessary for the liquefaction and separation process, it is necessary to supplement the cooling obtained from the expansion of the airstream with precooling. This precooling is done by using a mechanical refrigeration system (using freon), or by circulating nitrogen-rich air, cooled in an expansion turbine. Refrigeration is necessary to precool the airstream entering the liquefier

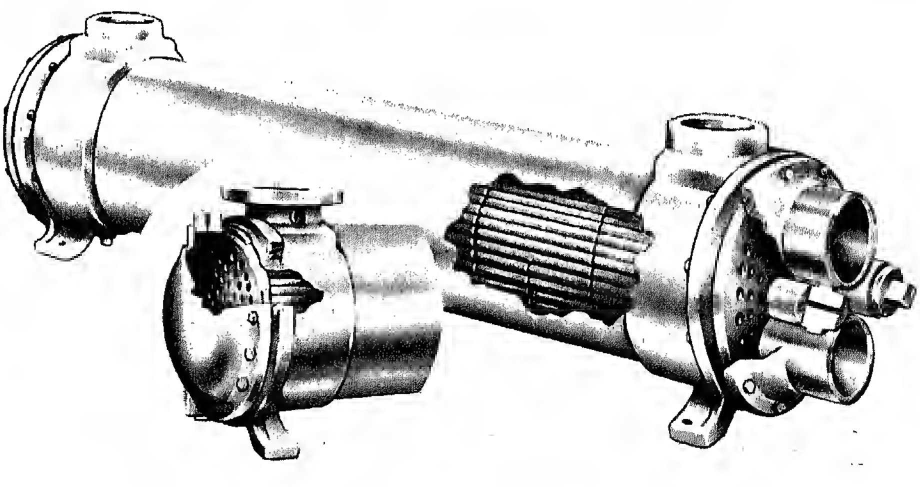


Figure 12. Cutaway view of a tube-and-shell heat exchanger.

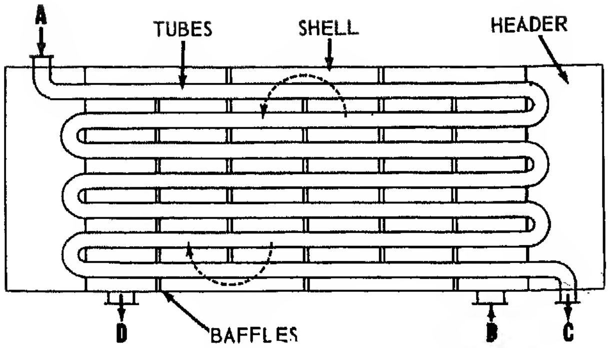


Figure 13. Single-pass heat exchanger.

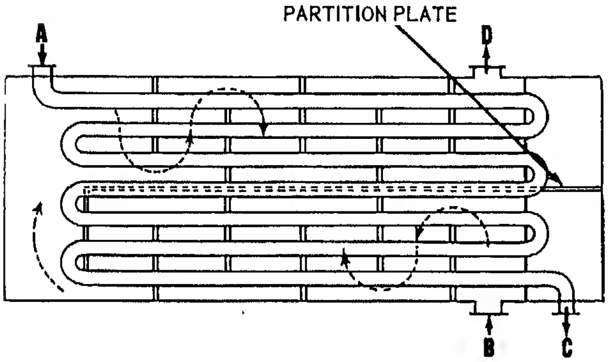


Figure 14. Multipass heat exchanger.

and, in some cases, to minimize the time required to bring the distillation column down to operating temperature.

a. High Pressure System. In a high-pressure system, a combination of external refrigeration and circulation of an effluent (nitrogen-rich) air is used. Refrigeration of air is provided by the expansion of the incoming air and by the circulation of an effluent air through heat exchangers with external refrigeration as an auxiliary coolant.

(1) *Expansion of air.* Compressed air, cooled to approximately —35°C. (—31°F.) in the second heat exchanger, enters an air cooler which uses freon as a refrigerant. The refrigerant, which has been compressed and condensed, is circulated through the shell of the air cooler in a direction opposite to that of the airstream. Transfer of heat from the airstream to the freon vaporizes the latter, which returns to the refrigerant compressor. The air, cooled to about —62°C. (—80°F.), passes from the air cooler to a third heat exchanger to continued reduction in temperature.

(2) *External refrigeration.* The external refrigeration system in most military plants is operated by a diesel-driven, two-stage compressor which compresses the vaporized refrigerant to about 150 to 225 psig. From the compressor the refrigerant flows to an air-cooled condenser where it is liquefied and returned to a receiver. The refrigerant flows from the receiver through two sub-coolers before passing through the air cooler where it accomplishes the desired refrigeration of the airstream. The refrigerant, vaporized by the heat from the airstream in the air cooler, then returns to the compressor, passing through the subcoolers en route. The vaporized refrigerant serves to supercool the liquid refrigerant in its countercurrent passage through the subcoolers and then cools the compressor lubricant in the oil cooler before being compressed and recirculated. Figure 15 is a diagram of a fluorocarbon refrigeration system.

b. Low-Pressure System. Refrigeration of air in the low pressure plant is provided by the nitrogen-rich air, separated from the liquid air in the phase separator, circulating through heat exchangers.

(1) *Reducing temperature.* To reduce the temperature of the nitrogen-rich air, an expansion turbine is used. The nitrogen-rich air expands as it passes through the turbine. Expansion of the gas mixture, accompanied by expenditure of energy, results in a reduction of temperature. Nitrogen-rich air enters the turbine (1, fig. 16) at a temperature of approximately —145°C. (—229°F.), and is discharged at a temperature of about —180°C. (—292°F.). This cold mixture is then passed through the heat exchangers to cool the incoming air.

(2) *Refrigeration.* For optimum efficiency, the expansion turbine rotates at about 13,000 rpm. Turbine speeds

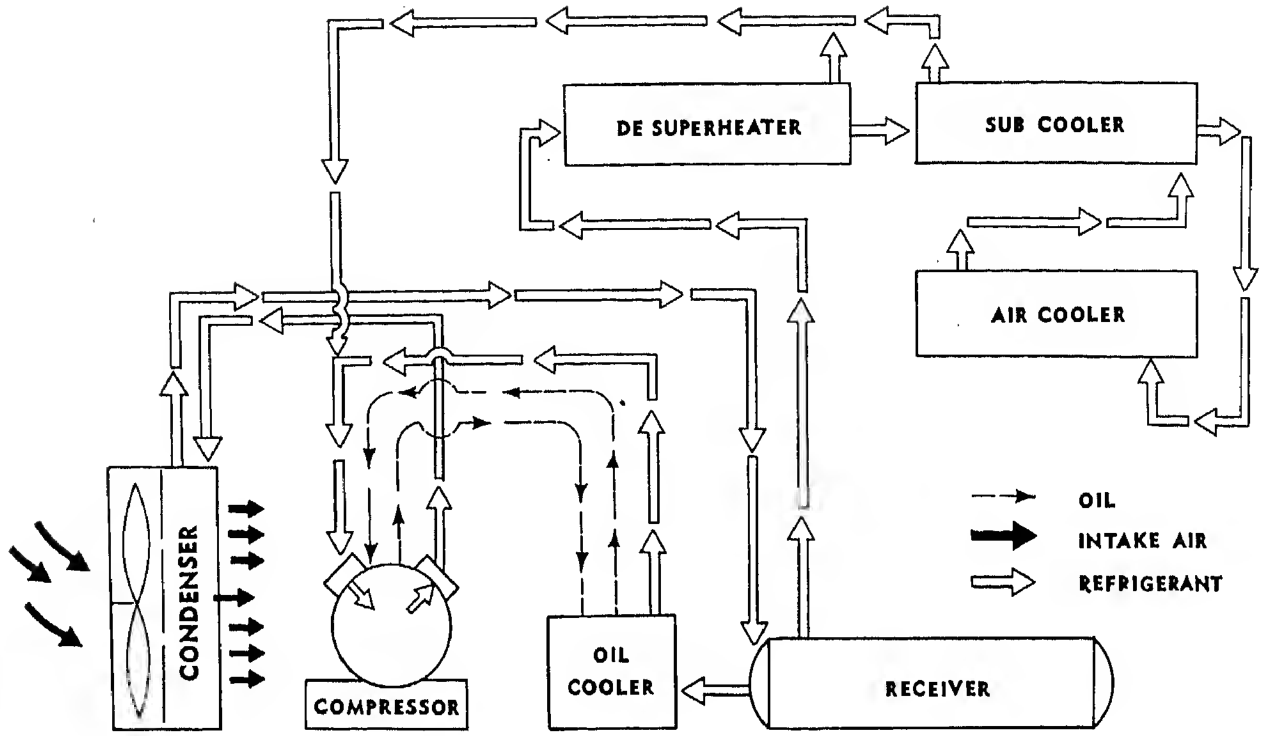


Figure 15. Fluorocarbon refrigeration system.

over 16,000 rpm are dangerous as the turbine may overheat and disintegrate. Refrigeration of nitrogen-rich air is obtained by extracting work from the expander turbine by a blower attached to the other end of its shaft (2, fig. 16). The blower also serves to govern the speed of the expander turbine. Further use of the brake airstream is made by inserting a lubricating oil cooler into the intake side of the blower and an air preheater into the exhaust side. When a warm plant is put into operation, the air going through the expansion turbine is not nitrogen enriched and is used to provide initial cooling of the liquefier and heat exchangers. The nitrogen-rich air only occurs after the temperature has dropped to cause liquefaction in the phase separator.

36. Low-Temperature Refrigeration

After precooling, as explained above, the next step is the extremely low temperature refrigeration necessary for liquefaction. There are two conventional methods for producing extremely low temperatures. The first, by rapid expansion of a compressed gas, is commonly termed the Joule-Thompson effect. The second, by allowing a compressed gas to perform external work (expanding the gas against a piston and thus converting the heat of compression to mechanical energy as the gas operates the piston), is known as the Claude process.

a. The Joule-Thompson Effect. The Joule-Thompson effect is currently used in the oxygen-nitrogen gas-generating unit (Ch. 2) for

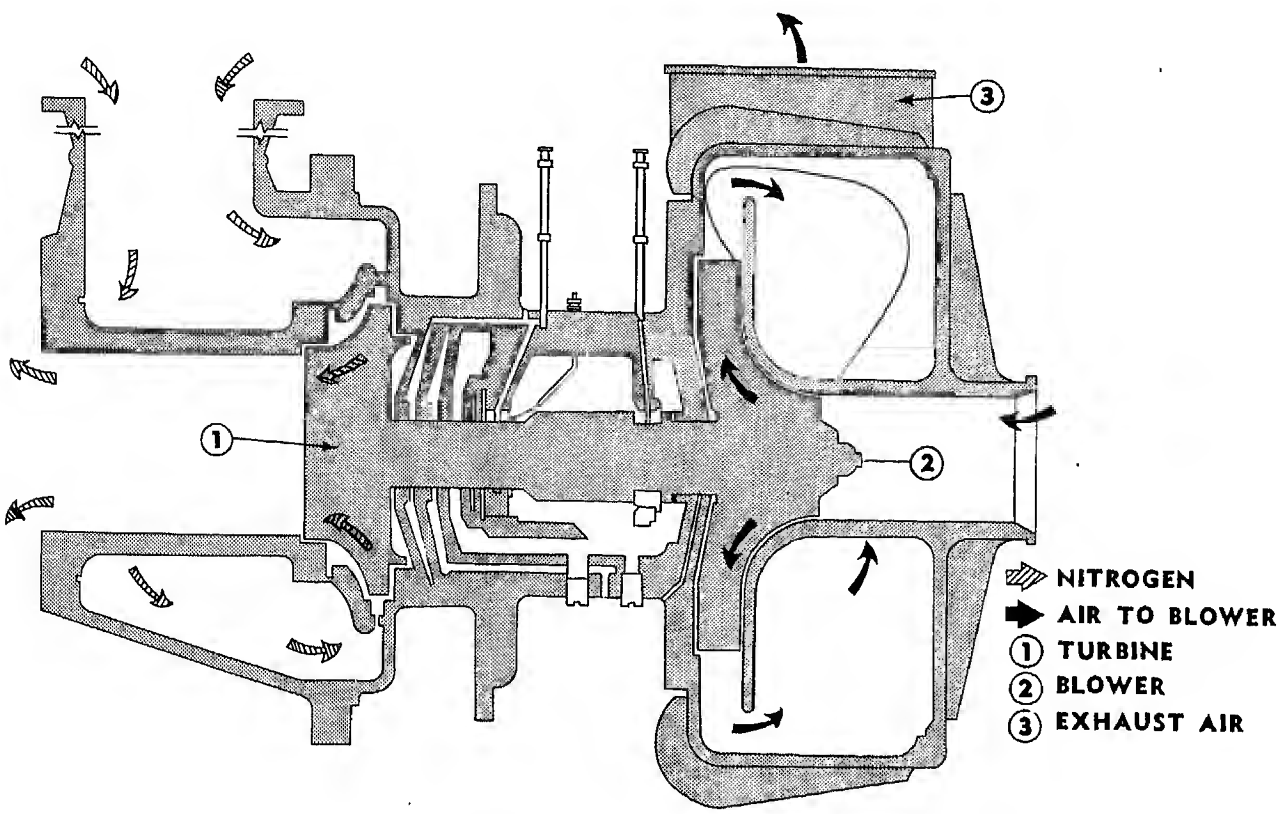


Figure 16. Expansion turbine.

producing extremely low temperatures necessary to liquefy a mixture of oxygen and nitrogen. The Joule-Thompson effect occurs when a real (nonideal) gas below a certain temperature (different for each gas) has its pressure reduced, resulting in a decrease in its temperature or has its pressure raised, resulting in an increase in its temperature. The greater the pressure change, the greater the temperature change. One method of using this effect is shown in figure 17. In figure 17 the gas from the compressor at high pressure and high ambient (surrounding) temperature flows through the heat exchanger (A–B) to the throttling pressure-reducing valve (B–C). Upon passing through the valve, the gas pressure is reduced and the resultant cooled gas is then recirculated in the heat exchanger (D–E) where it flows in the opposite direction to the gas entering at point A. This action precools the incoming high-pressure gas so that it may enter the throttling valve at a lower temperature than the original material. The gas is further cooled by passing through the throttle valve. This cycle is repeated until a heat balance is reached and an extremely low temperature is obtained. Since some form of mechanical compression is generally used to produce the high pressures in the first stage, the system is generally used with a mechanical refrigeration system rather than as an alternate to it.

b. The Claude Process. The Claude process uses the basic principle that work and heat are directly related, that is, to perform work, heat must be expended. Consequently, in the Claude process the high pressure gas to be cooled is allowed to partially expand against a piston. In moving the piston, the gas expends energy in the form of heat and is thus cooled. Actually, as shown in figure 18, the Claude process depends upon the Joule-Thompson effect for its final cooling and the work cycle is merely used to precool the gas.

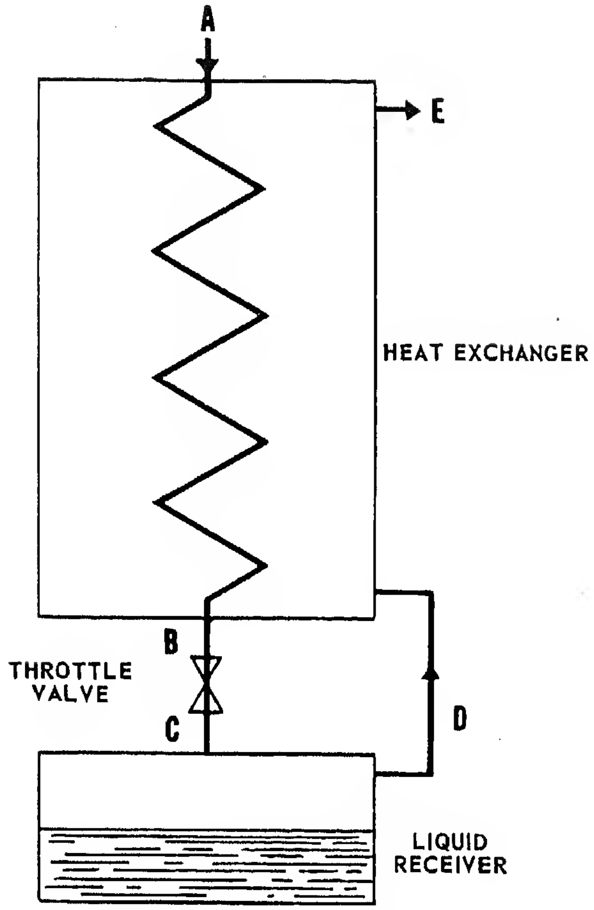


Figure 17. Joule-Thompson effect for low-temperature refrigeration.

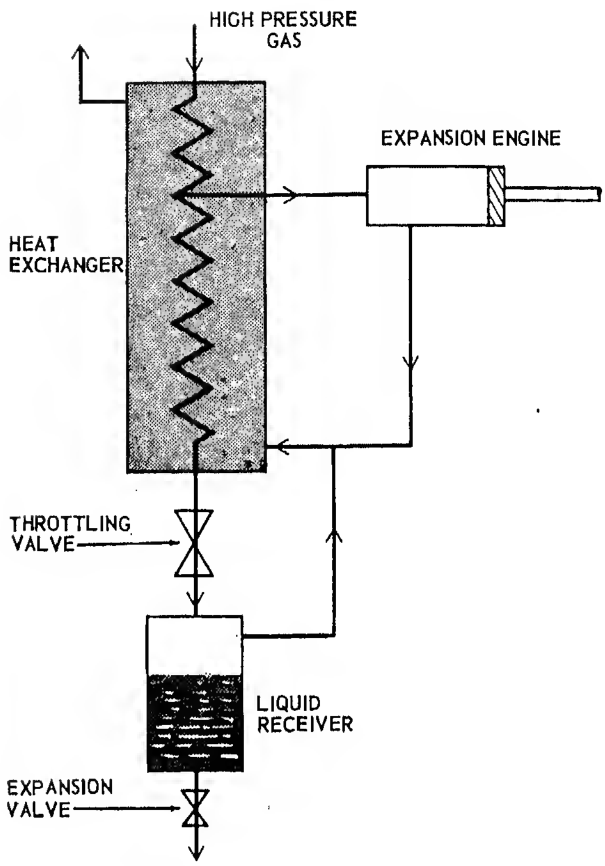


Figure 18. Claude process.

Section II. FRACTIONAL DISTILLATION OF LIQUID AIR

37. Generation of Oxygen and Nitrogen

a. Temperature-Pressure Relationship. In order to understand the phases of liquid oxygen production—compression, cooling, purification, liquefaction, and rectification—it is necessary to understand thoroughly the temperature-pressure relationship of gases. The temperature-pressure chart (fig. 19) shows for each gas the relationship between its critical temperature and critical pressure, (par. 32). The critical temperature is that temperature above which a gas cannot be liquefied, regardless of pressure. The critical pressure is the minimum pressure which will cause liquefaction to occur at critical temperatures. In order for gas to exist as a liquid, its temperature must be reduced to a point below its critical temperature. A gas may be liquefied at its critical temperature by compressing it to its critical pressure. However, as the temperature of the gas is reduced, less pressure is required to obtain the liquid state. For example, water (H_2O) has a critical temperature of 373+°C. (705+°F.) and a critical pressure of 3,200 psia (pounds per square inch absolute pressure), but at 100°C. (212°F.) it exists as a liquid at 14.7 psia. It may be seen, then, that for a gas to exist as a liquid, the proper temperature-pressure relationship must prevail. Any gas may be liquefied by reducing it to a temperature below its boiling point at the existing pressure.

b. Equipment. The liquid oxygen equipment currently used by the Armed Forces of the United States is classified according to the air

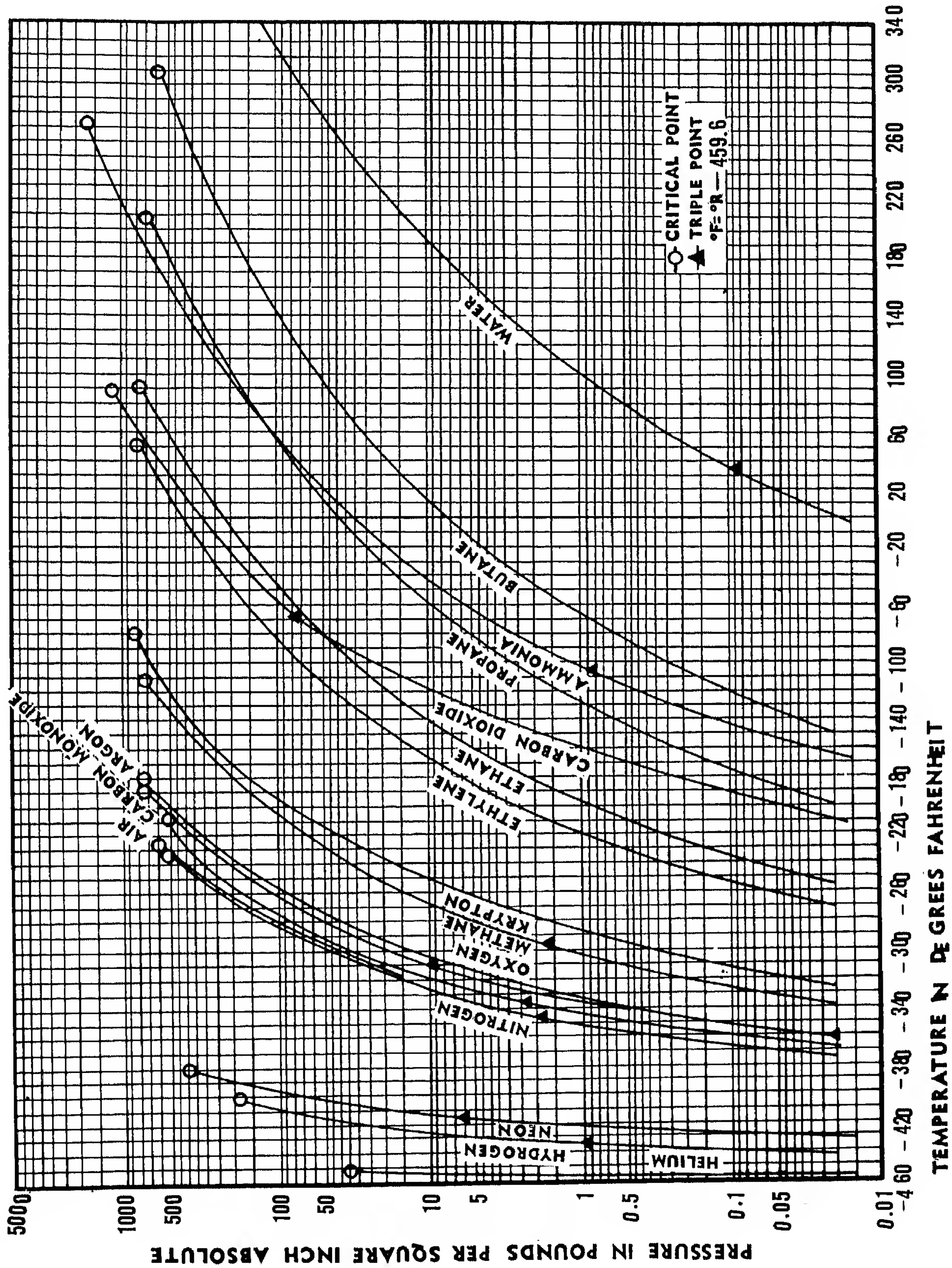


Figure 19. Temperature-pressure chart.

pressure used in the liquid oxygen process and the production capacity. Typical are the high pressure plant with a 5-ton-per-day capacity (figs. 20 and 21), and the low pressure plant with a 20-ton-per-day capacity (figs. 22 and 23). These two plants are used for the generation of liquid only; liquid is used in missiles. To generate gases, which are used mostly for industrial purposes such as welding, there is the A-2 plant (figs. 24, 25, and 26).

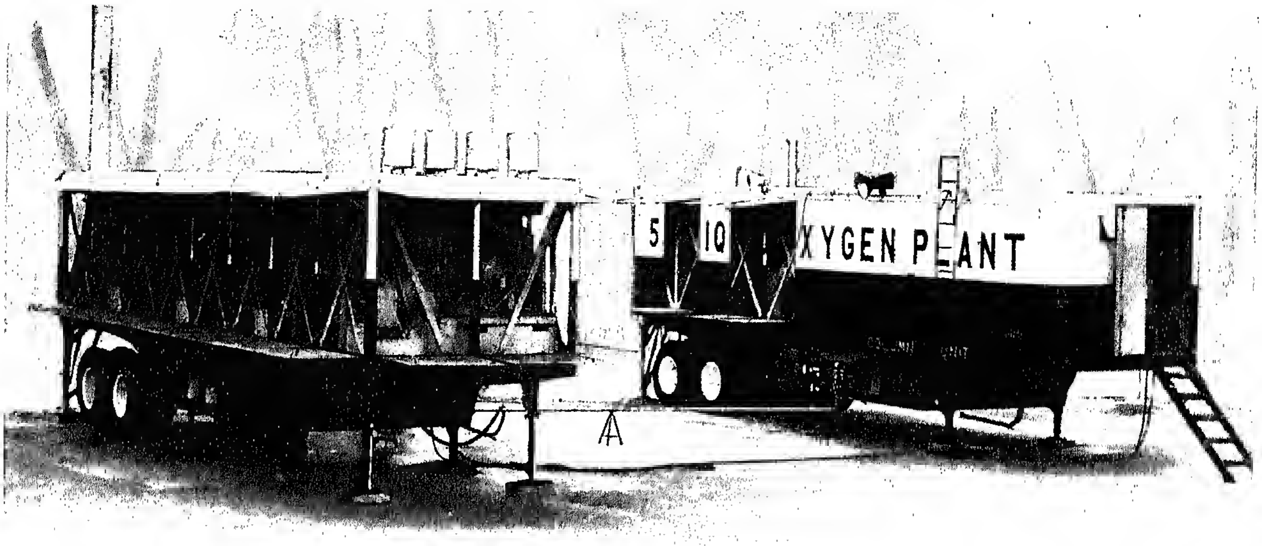


Figure 20. 5-ton plant.

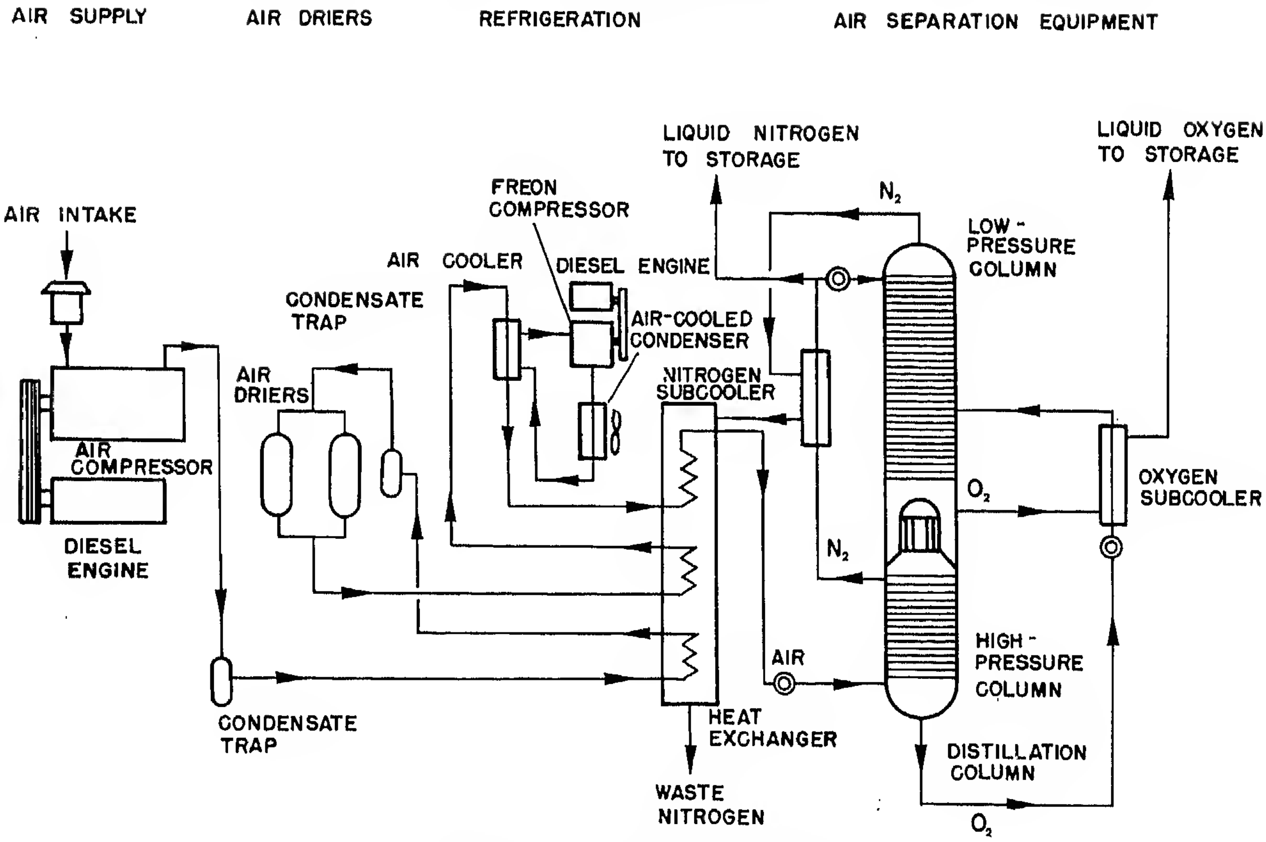


Figure 21. Flow chart for 5-ton plant.

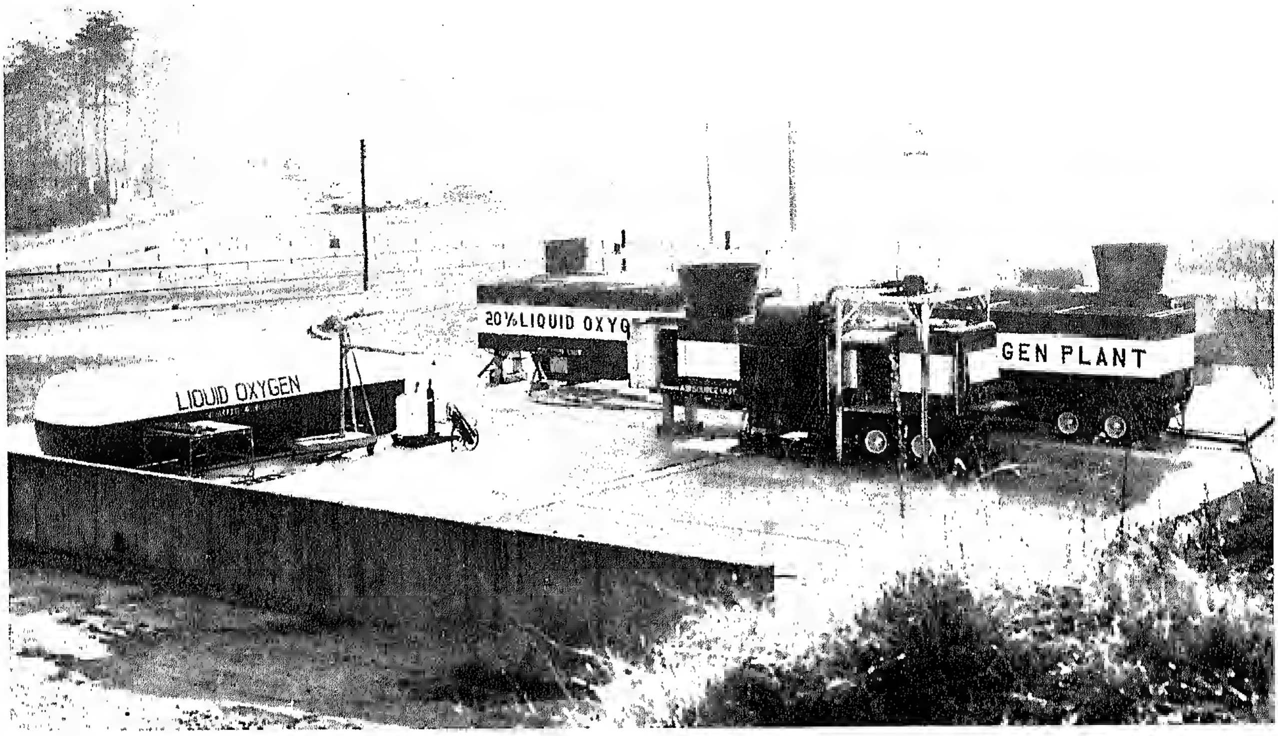


Figure 22. 20-ton plant.

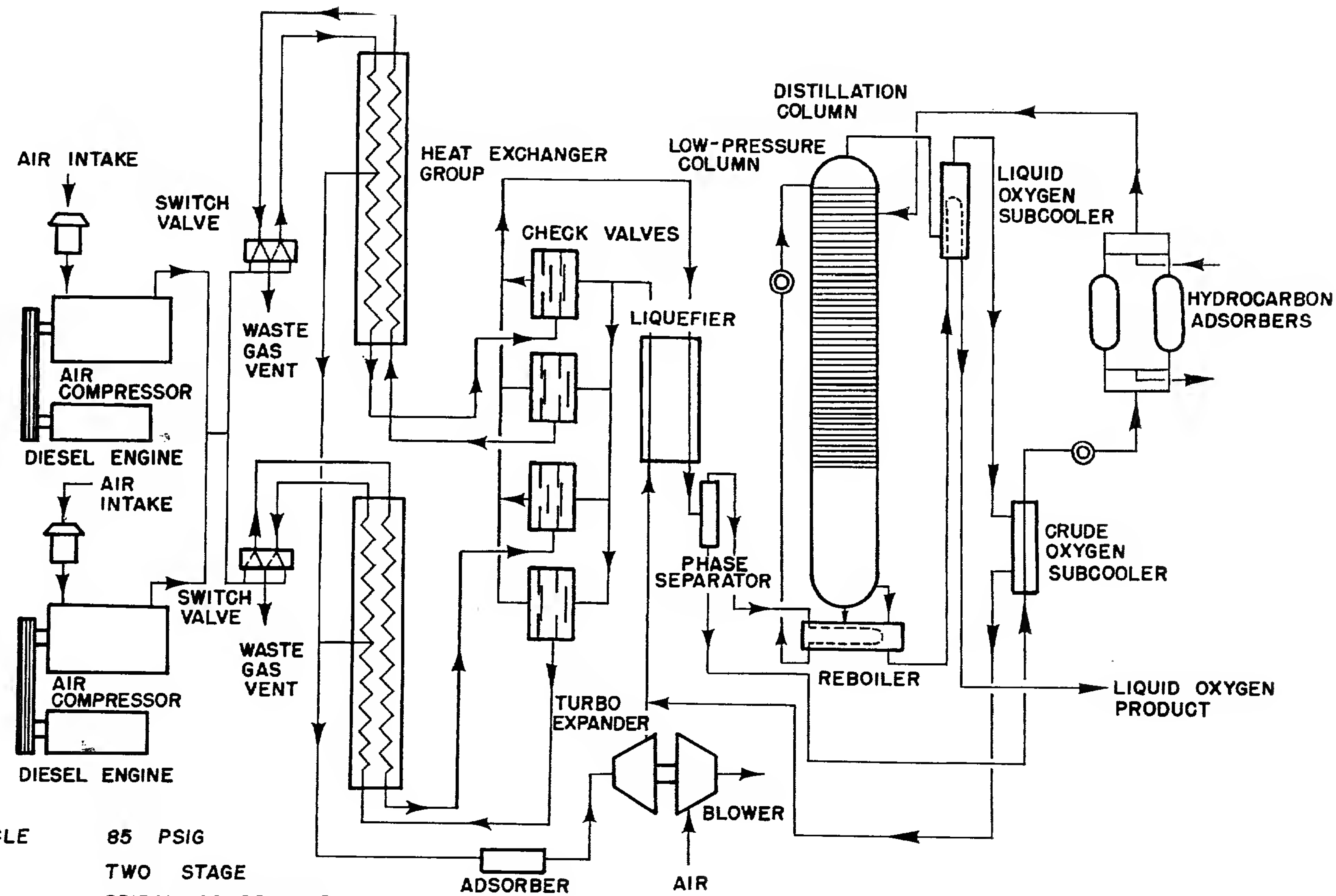
c. Processes. All oxygen and nitrogen plants using the fractional distillation of air process perform the operations described in paragraphs 38-43 below. Although there are basically no major differences in the overall operation, various gas plant manufacturers differ in the methods and design of the production equipment. This is especially true in the design of equipment used in the production of the extremely low temperatures required. In general, two types of processes are used for this purpose, the Linde process and the Claude process, each of which is named after the individual responsible for its introduction.

38. Compression

A typical system for the generation of oxygen and nitrogen by the Linde process can be traced by reference to figure 26. The first major step in the generation process is the compression of air. Initially, in a compressor similar to that shown in figure 27, air is drawn into a filter similar to the type used on an automobile carburetor. The filter removes the dust before the air enters the first stage of the compressor. The pressure of the gas is increased through each of the compressor stages as shown until the gas leaves the final stage at a pressure high enough to be readily liquefied when it is cooled below its critical temperature later in the process. In most gas-generating systems this will be approximately 3,000 psig. After each stage of compression an air- or water-cooled intercooler (called an aftercooler after the final stage) and a condensate trap are provided as shown to remove the heat of compression and also the moisture from the air.

a. Compressors. There are many sizes, shapes, and designs of compressors, but in the Armed Forces the two types used are classed as reciprocating and rotary.

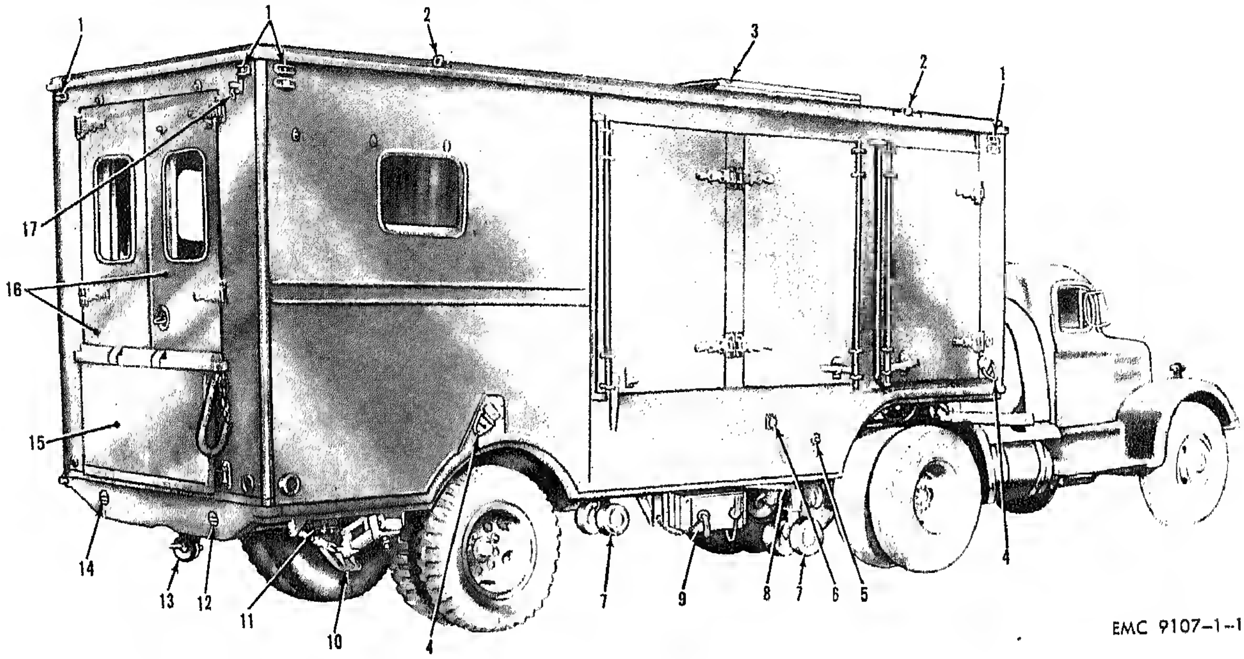
(1) *Reciprocating.* A schematic diagram of a reciprocating compressor is shown in figure 28. It is used in the 5-ton and A-2 plants. The piston (P) slides within the bore of the cylinder (CL) as the piston is driven through the crankshaft (CS) and the connecting rod (CR). A reciprocating com-



CYCLE 85 PSIG
TWO STAGE
SPIRAL COMPRESSOR
POSITIVE DISPLACEMENT
5200 SCFM

CAPACITY LIQUID OXYGEN 20 T/D

Figure 23. Flow chart for 20-ton plant.



1 Clearance lights
2 Roof lifting eyes
3 Roof hatch
4 Semitrailer lifting eyes
5 Landing gear crankshaft
6 117-volt receptacle
7 Landing gear
8 Parking brake lever
9 Jack and landing gear cradler and planks
10 Leveling jack
11 440-volt receptacle
12 Blackout stoplight and blackout taillight
13 Pintle hook
14 Service stoplight, service taillight, and blackout taillight
15 Tailgate
16 Rear doors
17 Oxygen-nitrogen charging line connection

Figure 24. Semitrailer and tractor for A-2 plant.

pressor can be either of a single-acting (as shown) or a double-acting type. The inlet valve (IV) and the discharge valve (DV) are placed in the cylinder head and connect respectively to the suction line (S) and the discharge line (D). The flow of vapor is shown by the arrows placed at the end of these lines. It will be noted that the vapor is compressed at one end of the cylinder and that, as a result, there is only one compression to each revolution. The inlet valve (IV) is opened by the suction of the piston on the downstroke and is closed by a valve spring at the end of the suction stroke. The discharge valve (DV) is opened by the piston compression and is closed by a valve spring after the compression stroke is completed.

(2) *Rotary.*

(*a*) A schematic diagram of one type of rotary compressor is shown in figure 29. As shown it is without valves and therefore can be driven at high speeds without any trouble. However, it is difficult to seal internally against leakage, has a great deal of friction, and therefore consumes a great deal of power. Essentially the compressor consists of an outer cylindrical casing (C) bored accu-

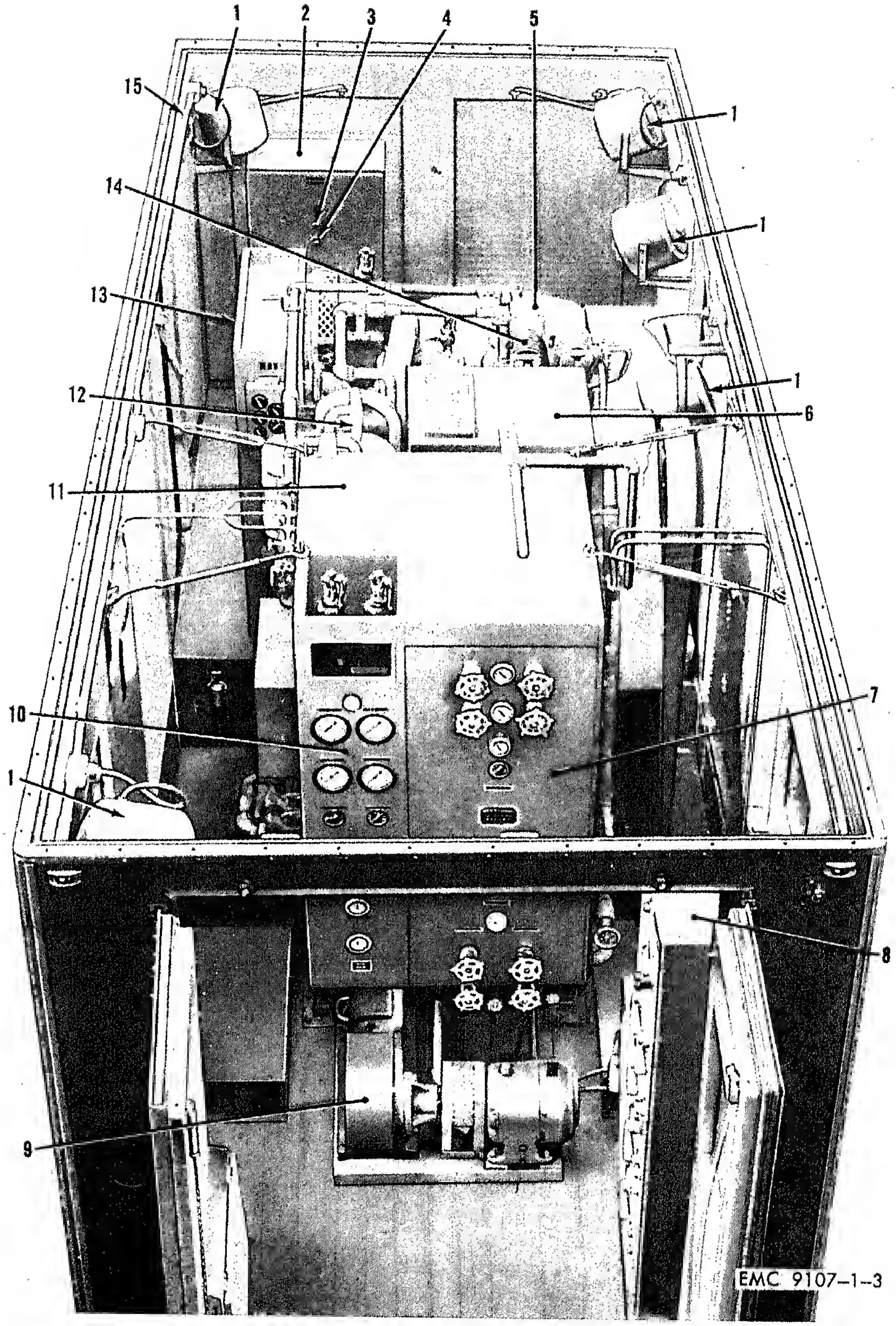


Figure 25. A–2 plant (top view of semitrailer).

1 Equipment heaters
2 100-hp motor starter
3 100-hp motor START button
4 100-hp motor STOP button
5 100-hp motor
6 Air refrigerator
7 Air drier instrument panel
8 Motor control center
9 Oxygen-nitrogen pump
10 Air separator instrument panel
11 Air separator
12 Air purifier
13 Intercooler-aftercooler
14 Air compressor
15 Power conduit

Figure 25—Continued.

rately to a circular track. Inside this casing is the rotor (R) of cylindrical form which turns on the shaft (M). It will be seen that the center of the rotor and rotor shaft are not on the center of the casing. Therefore, one rotor is eccentric with the casing bore. The rotor bottom very closely fits the bottom of the casing track, not actually touching the bore but only a few thousandths of an inch from contacting the surface. The amount of vapor compressed depends upon the difference between the diameters of the rotor and the bore of the casing. Inserted in the rotor, and free to slide back and forth, are the two sliding vanes (V1 and V2) that contact the bore at their outer end. These vanes are actually the pistons of the compressor and therefore the outer ends of the vanes are forced against the bore by springs in the rotor. The springs are assisted by centrifugal force when the compressor is running so that a firm contact is made. The sliding action of the vanes accommodates their effective length at different parts of the revolution, the total amount of vane travel being at a maximum at V1 and at a minimum at V2. When the rotor revolves from left to right in the direction of the arrow, the volume of the space (a) on the left of the vane (V1) increases while the space on the right (b) decreases. This means that there is a decrease in pressure in the area of (a) creating the suction while the pressure is increased in the area of (b), the compression. Area (a) is the low side while area (b) is the high side. The suction inlet is shown at (S) and the discharge outlet at (D). Vapor is drawn into the compressor at (S), passes around with the vane (V1) to the right, then is compressed in the area (b) and is finally discharged through the discharge connection (D). Increasing the number of vanes increases the operating efficiency of the compressor.

(*b*) Another type of rotary compressor is the lobe type (fig. 30).

b. Compressor Staging Design. Compressors are of either single-stage or multistage design.

(1) *Single stage.* Single-stage compressors have only one impeller or piston and the pressure therefore cannot be increased beyond the working maximum of the compressor.

(2) *Multistage.* In a multistage compressor this disadvantage is overcome by combining several single-stage pumps so that the discharge of one compressor is delivered to the suction of the next. The gas is delivered to each stage under the pressure given to it by the preceding stage, and more pressure is added. A much higher working head can be produced than is possible in a single-stage compressor. The units under consideration do not have more than four stages.

c. Coolers. The Joule-Thompson effect causes a rise in temperature with each stage of compression. Consequently, after each stage of compression a means of cooling is provided to reduce the temperature by removing what is termed the heat of compression. When this cooler is located between two successive stages of compression, it is termed an intercooler.

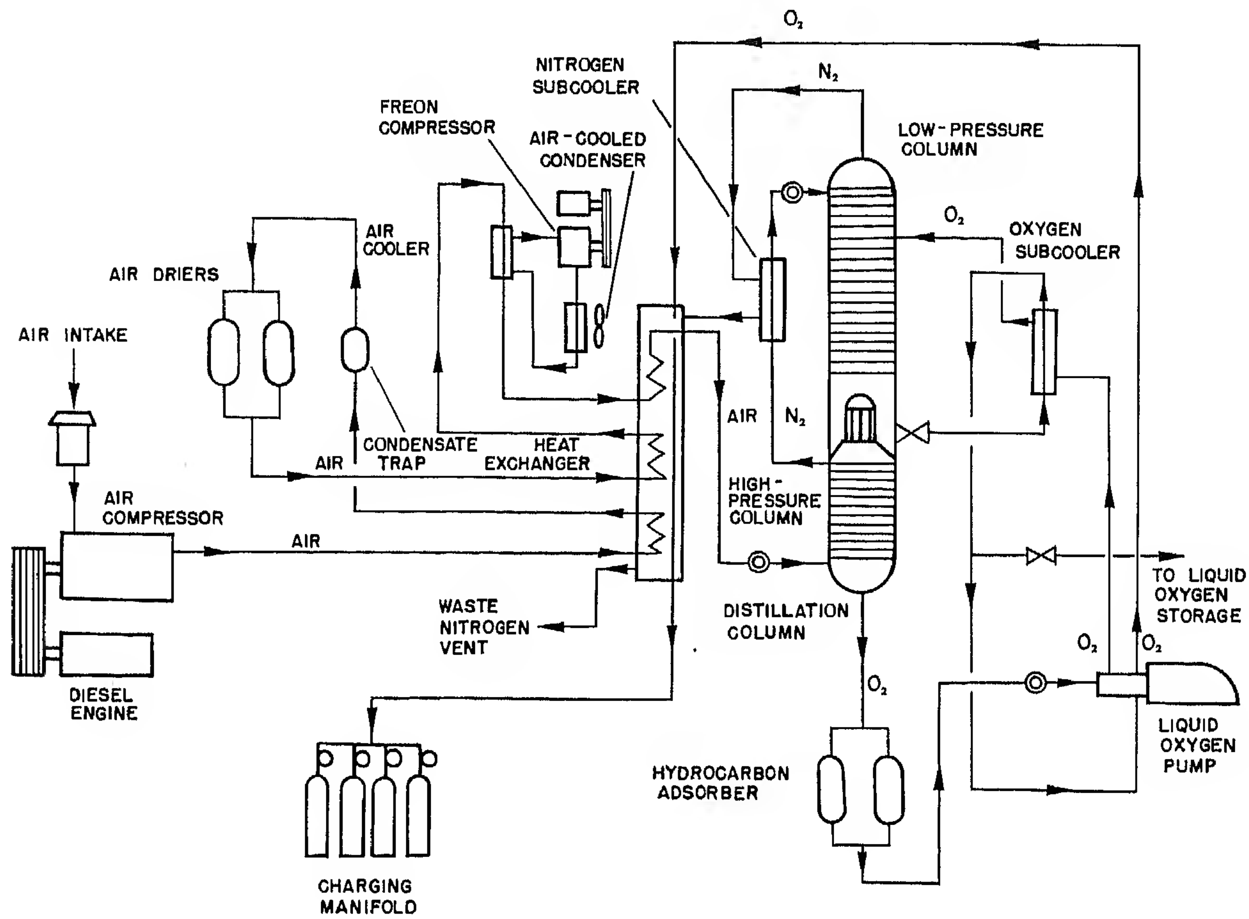


Figure 26. Flow chart for A–2 plant.

When it follows the last stage of compression, it is termed an aftercooler. For example, a three-stage compressor would have two intercoolers and one aftercooler.

39. Cooling

To liquefy the air which has been compressed and has an extremely low critical temperature of —146° C. (—231° F.), the air must be further cooled. As this reduction in temperature cannot be accomplished by a conventional refrigeration system, cold liquid oxygen and nitrogen from the rectification section of the distillation column are used in extracting the heat from the air. This is generally done in a 3-stage shell-and-tube heat exchanger of a type similar to that shown in the schematic diagram in figure 31 and in cross section view in figure 32. Air from the compressor aftercooler passes into the first section of the heat exchanger where it comes in contact with the cold oxygen and nitrogen flow. No attempt is made in first stage of heat exchange to lower the air temperature below 4.4° C. (40° F.) because all the moisture has not as yet been removed from the air and the danger of line freezeup and consequent plant shutdown is still present. Consequently, air from the first stage of the heat exchanger is passed into a dryer or adsorber filled with an adsorbing agent such as silica gel as shown in figures 33 and 34. There are basically two such dryers connected in parallel so that they can be alternately used and regenerated during plant operation, that is, one can be used while the water is being removed from the adsorbing agent in the other to restore its adsorbing power. From the dryer (fig. 26), the dry air enters the second stage of the heat exchanger where the temperature is further reduced to approximately —18° C. (0° F.) by a

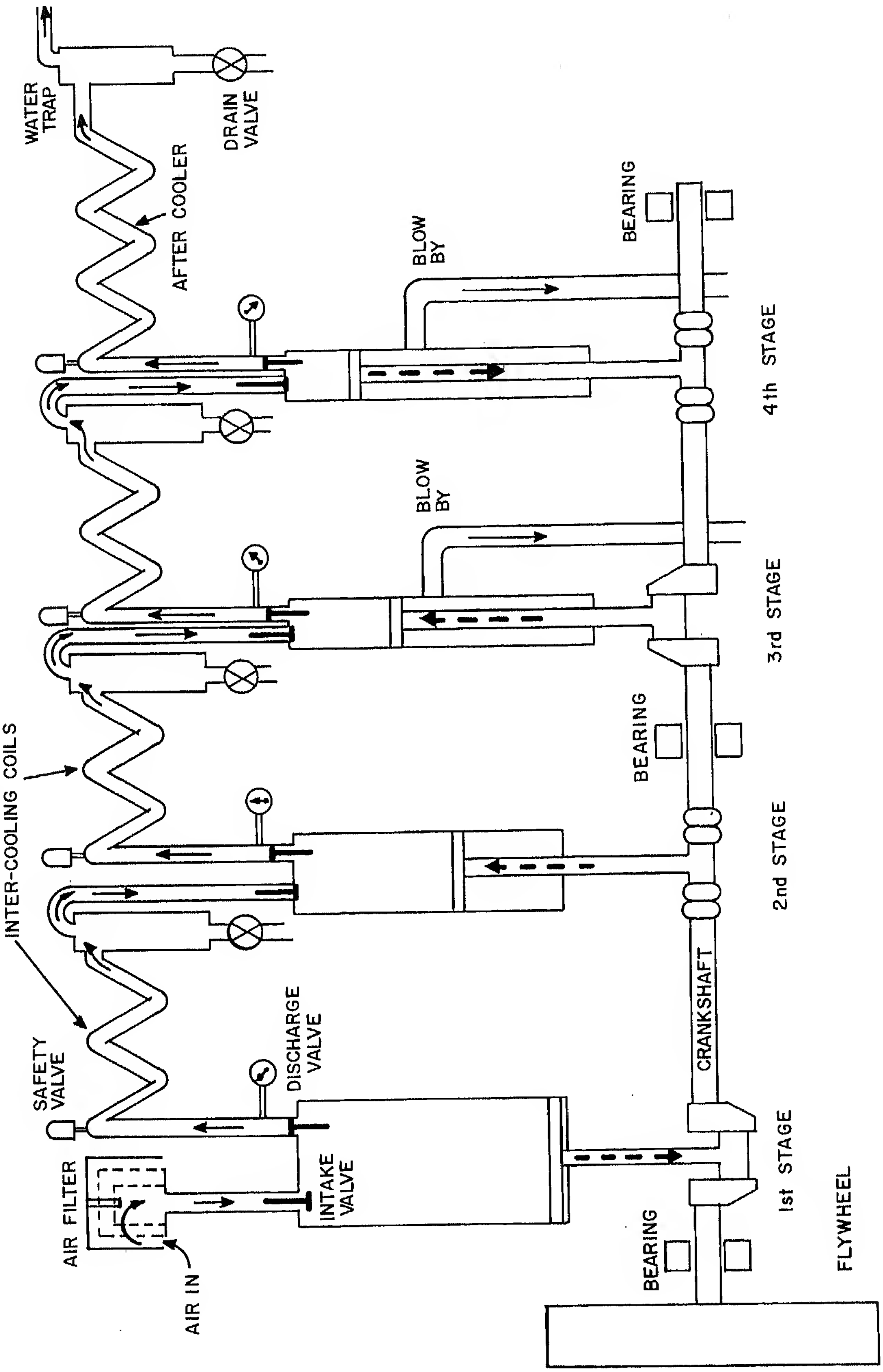


Figure 27. Compression cycle.

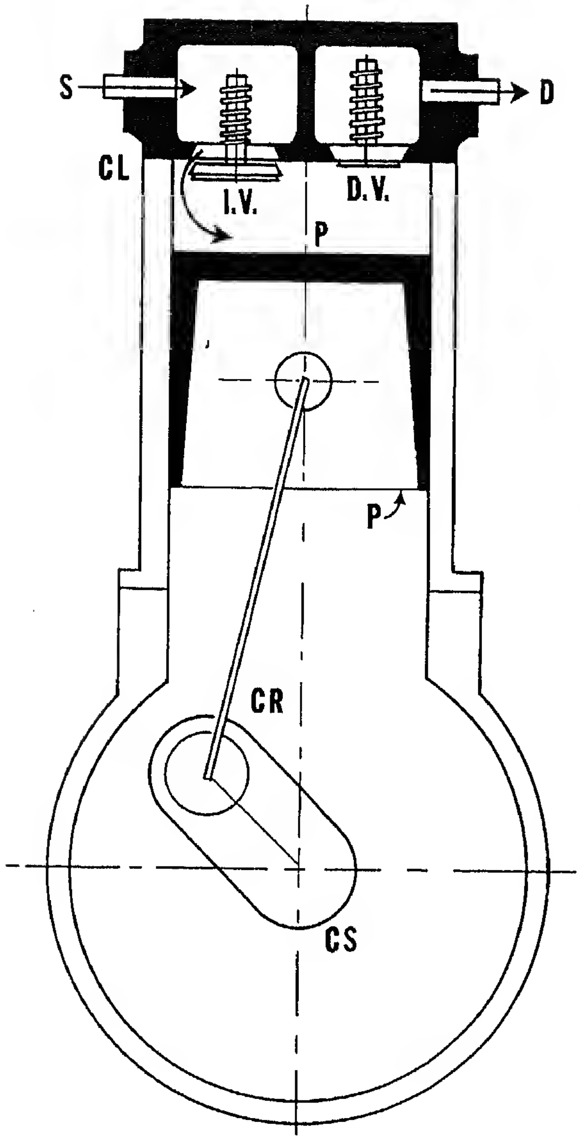


Figure 28. Reciprocating compressor.

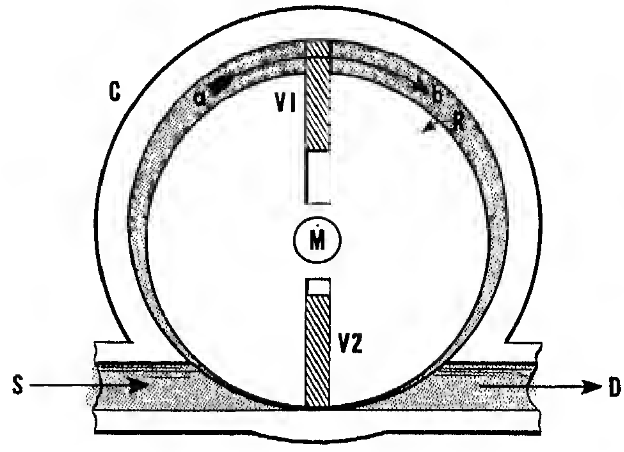


Figure 29. Rotary compressor.

imilar interchange of heat from air to oxygen ınd nitrogen as in stage 1. Most plant manu-facturers use a mechanical refrigeration sys-em as shown in figure 26 in conjunction with he second stage of heat exchange. This pro-vides an auxiliary cooling system for increased efficiency and reduces the required operating time, on startup, before high-purity oxygen and nitrogen are produced. As the air gives up its heat to the liquid refrigerant in the evaporator of the refrigeration system, the air temperature drops to approximately —40° C. (—40° F.). From the evaporator the air enters the third stage of the exchanger where it contacts extremely cold liquid oxygen and nitrogen which has just left the distillation column. Through contact, the air temperature is further reduced to approximately —84° C. (—120° F.). From the last section of the heat exchanger the cold air is reduced from its initial 3,000 psig to between 60 and 80 psig by the use of an expansion valve. Because of the Joule-Thompson effect, this sudden expansion is accompanied by a reduction in temperature of the air to approximately —179° C. (—290° F.). At this temperature and pressure the air will liquefy and the air is now ready to enter the rectification column or air separation system.

40. Purification

One of the major operations or series of operations in any gas-generation process is the cleaning and purifying of the manufactured gas. Gas impurities, usually in suspension in the gas, either originate from the raw materials or are introduced during the generation process. For example, in the manufacture of oxygen, the air used in the generating process has many impurities (dust, soot, water vapor, and so on) which must be removed during manufacture. Moreover, water is used in many of the operations, and since the resultant water vapor is an undesirable impurity in the end

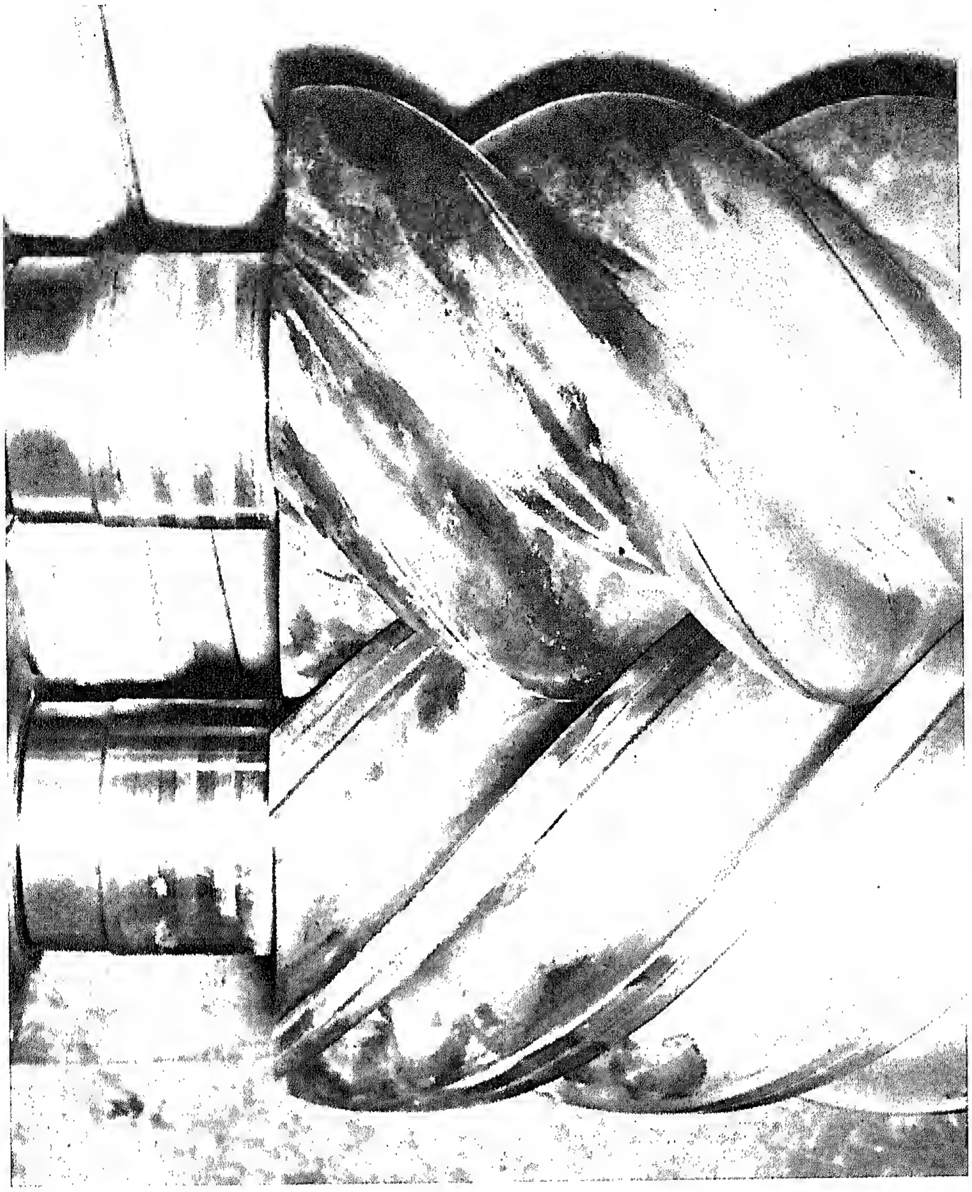


Figure 30. Lobe type compressor.

product, it also must be removed. On occasion, the impurities cleaned or separated from the gases manufactured are valuable byproducts. However, these instances are in the minority and most of the time the impurities are disposed of by any convenient means, such as dumping them in a pit or stream, or venting the gases to the atmosphere. Several types of equipment are used in cleaning and purifying oxygen and nitrogen. These are filters, adsorption dryers, and scrubbers.

a. Filters. Filters are probably the simplest type of equipment used for removing gas impurities and should be familiar because of their universal application in such common machines and mechanisms as automobile engines or forced-air furnaces. Essentially they consist of a framework which holds a material such as fiberglas or steel wool and metal baffles which remove dirt or dust in the air. Filters of this design are either the permanent type which can be washed and reused or the disposable type which must be replaced periodically.

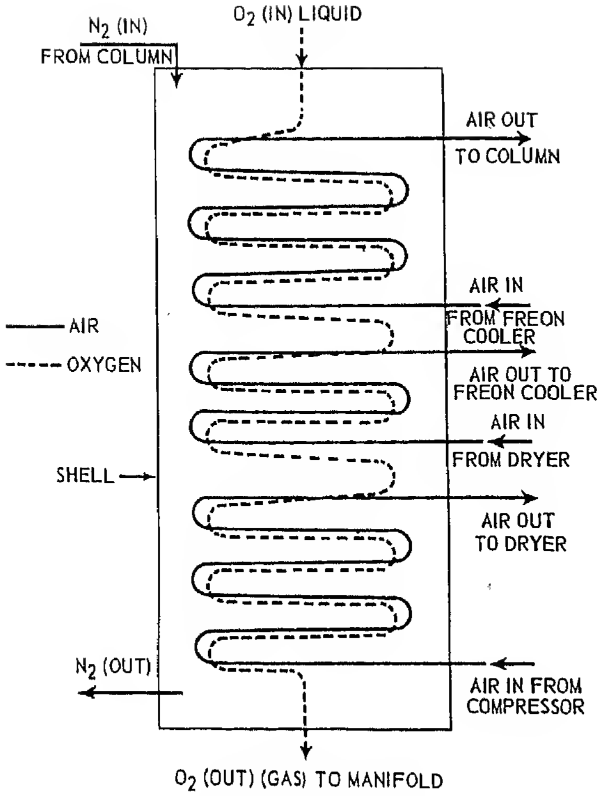


Figure 31. Cooling cycle.

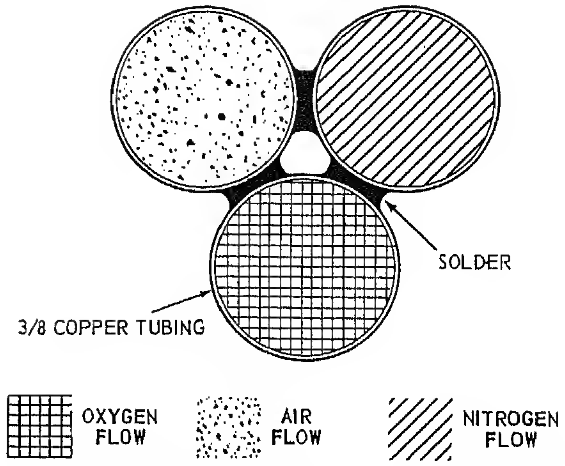


Figure 32. Sectional view of gas flow through heat exchanger tubes.

b. Adsorption. In the 5-ton and 20-ton plants the purification process, which uses the property of molecular adhesion for removing impurities from a gas, is called cleaning by adsorption. A common application of adsorption systems in gas generators is the removal of water vapor from the end product. The adsorbing agent most commonly used is a solid

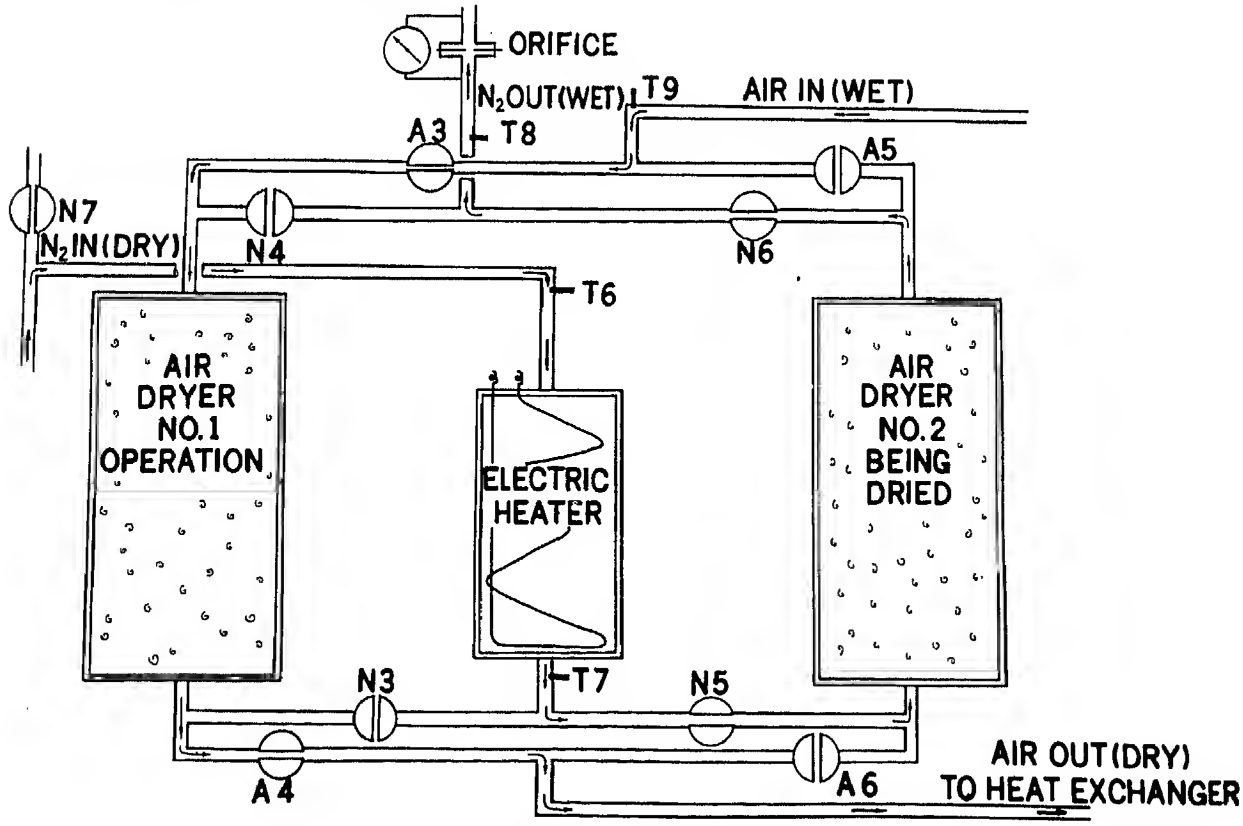


Figure 33. Drying cycle.

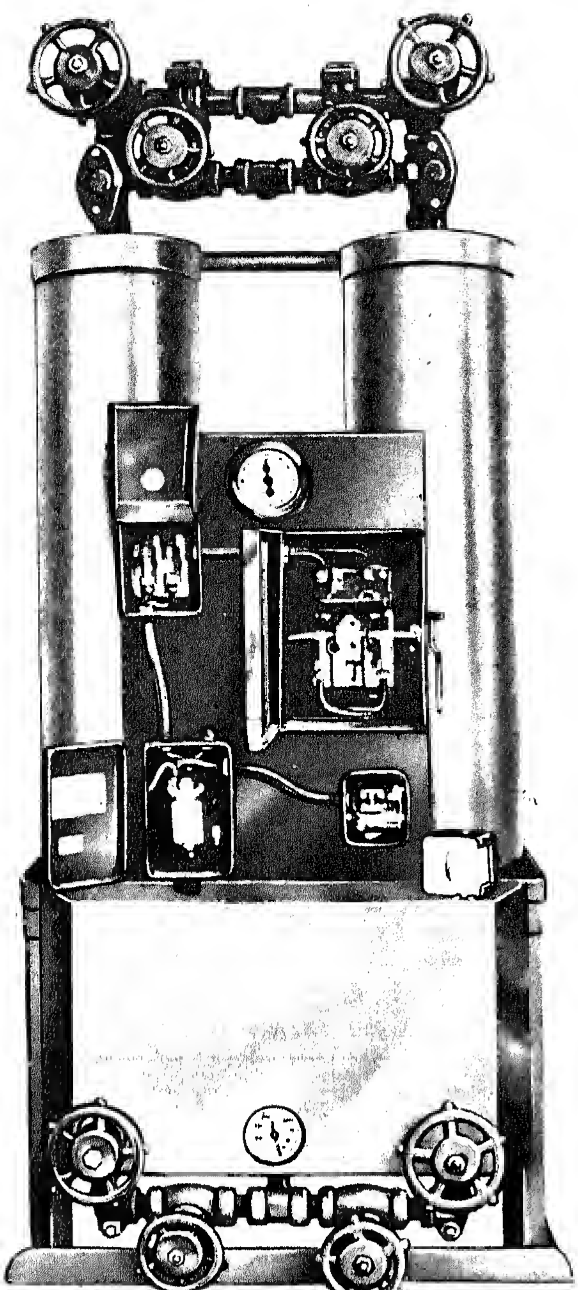


Figure 34. View of dryer.

substance called silica gel which has the peculiar property of adsorbing and holding a large amount of water per unit weight of gel. A typical silica gel dryer is cylindrical and packed with the absorbing agent. The gas to be dried enters the bottom or top of the cylinder, depending on dryer design. As the gas is drawn upward (or flows downward) through the solid desiccant or drying agent, the water vapor is deposited on the silica gel, thus drying the gas. Usually two dryers are connected in parallel in a generating system and are alternately used. This permits continuous gas generation without interruption for dryer reactivation. The dryer is reactivated by passing warm dry air over the bed of the drying agent to remove the water vapor absorbed from the gas. Figure 35 illustrates a typical dryer installation. Table IV lists some of the common adsorption agents used and their properties. In the gas generating units presently used by the Army, silica gel or activated alumina (powdered aluminum oxide) are most commonly used as drying agents.

c. Scrubbing.

(1) *A-2 plant.* In the A-2 plant, before the compression cycle is completed, the air is passed through caustic scrubbers as shown in figure 36. This removes the carbon dioxide in the air, which would cause freezeup of the unit when the gas temperature is reduced during the latter stages of the process. The air is processed through the scrubbers between intermediate

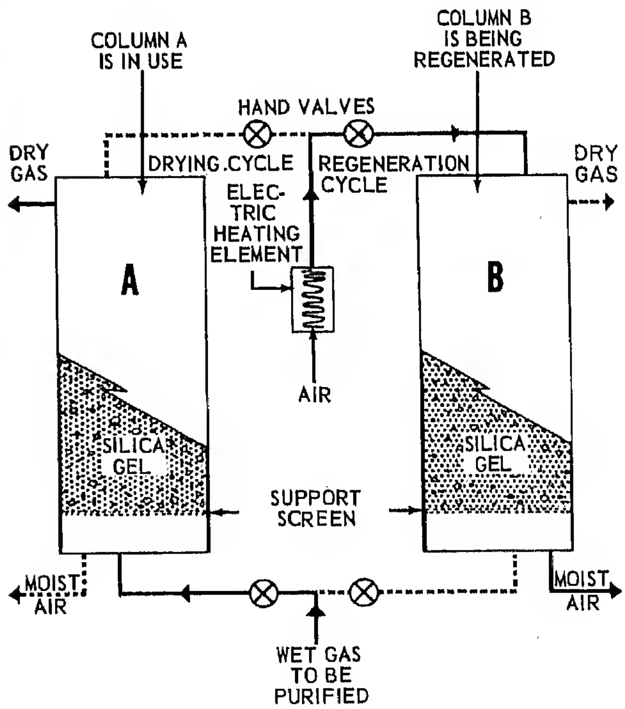


Figure 35. Typical adsorption system.

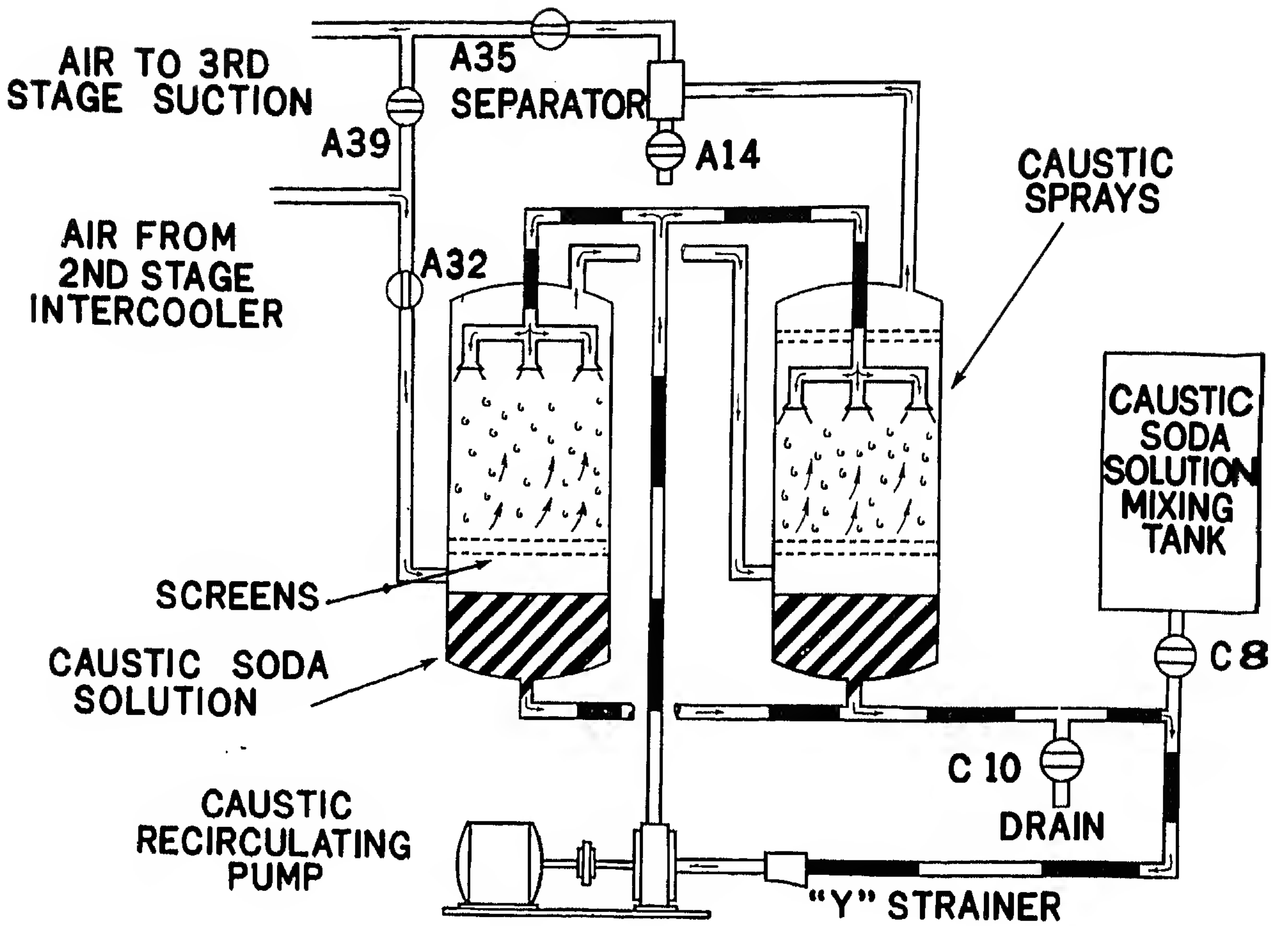


Figure 36. Scrubbing cycle.

Table IV. Properties of Solid Adsorbents

Properties	Activated carbon	Activated alumina	Silica gel
Apparent density	0.7–0.9	1.6	0.7
Specific gravity	1.75–2.1	3.25–3.35	2.1–2.3
Average wt, lb per cu ft	28–34	50	38–40
Reactivation temperature	220–240° F.	350–600° F.	300–350° F.
Reactivation method:			
Live steam	X	--------	--------
Preheated gas or air	--------	X	X
Flue gas	--------	X	X
Embedded elec. heaters	X	X	X
Embedded steam coils	X	X	X
Weight of water at saturation, %, dry basis	--------	20–25	40
Applications:			
Drying air	--------	X	X
Drying nonreactive gases	--------	X	X
Drying reactive gases	--------	--------	X
Gas and air conditioning	--------	X	X
Gaseous fuel drying	--------	X	X
Odor, taste removal from CO_2	X	--------	--------
Abatement of putrid odors	X	--------	--------

Note. X indicates absorbent should be used.

compressor stages, usually after the air leaves the second stage of compression and before it enters the third stage. For efficiency, two scrubbers are piped in series. The towers are drained and a new scrubbing agent added as the agent becomes fouled, that is, when it becomes saturated and can no longer absorb carbon dioxide. The scrubbers are generally packed type towers and use a caustic solution absorbing agent of sodium or potassium hydroxide. Sodium hydroxide (NaOH) is preferred since it has a high affinity for carbon dioxide and is relatively inexpensive. The chemical reaction in the scrubbers is as follows:

$$2\,NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$

(2) *5-ton and 20-ton plants.* In these plants crude liquid oxygen from the phase separator is purified of its hydrocarbon, CO_2, and other impurities by passing it through an adsorber before rectification. The hydrocarbon adsorber is normally mounted as a double unit in parallel to permit bypassing and reactivation of a saturated unit while the other is in use (fig. 37). The vessels are cylindrical and are filled with a desiccant such as silica gel and/or activated alumina. The adsorbers in the high pressure (5-ton) system differ from those in the low pressure (20-ton) in that they contain, in addition to the desiccant, porous bronze filters for filtering out particles of solidified carbon dioxide. Acetylene and other hydrocarbons, which entered as impurities in the air feed, are adsorbed by the desiccant. If the concentration of impurities in the air feed is not too high and the adsorber is serviced properly in relation to the concentration, the adsorber prevents a hazardous accumulation of hydrocarbons in the rectification column.

41. Liquefaction

Liquefaction of the air is the major job in producing liquid oxygen. Air liquefies when proper conditions of temperature and pressure exist. To introduce this operation, it is necessary to note that the Joule-Thompson effect can liquefy a gas if the temperature is low enough to obtain the effect, and if the pressure drop is great enough. Therefore, by compressing and cooling air, then expanding it suddenly, the temperature will drop below the boiling point of air and liquefaction will occur.

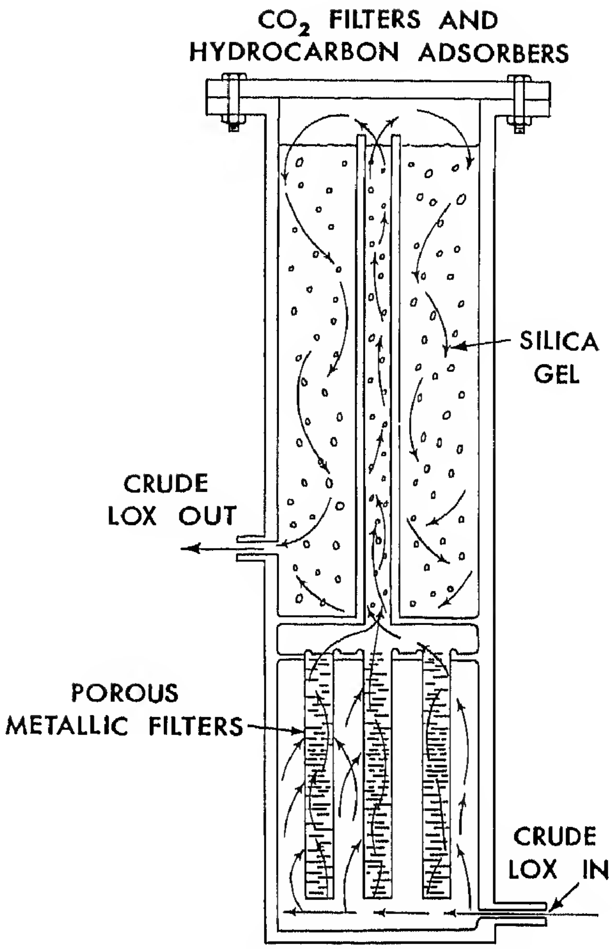


Figure 37. Drying cycle in typical adsorber.

a. Process.

(1) *High pressure system.* Air passing through the third, or cold, heat exchanger in the high pressure plant is reduced in temperature to approximately —123° C. (—190° F.), and is under approximately 3,000 psig pressure. The air temperature is a little below the critical point and pressure is well in excess of the level to produce liquefaction. This cold airstream

then passes through an expansion valve where the pressure is suddenly reduced from 3,000 psig to about 70 psig. Along with this pressure drop is a reduction in temperature to approximately –179° C. (–290° F.), which liquefies part of the airstream.

(2) *Low pressure system.* In the low pressure plant, liquefaction occurs in a third heat exchanger or liquefier. Air from the second heat exchanger enters the liquefying exchanger at about –170° C. (–274° F.). In the liquefier, the temperature of the air is further reduced, by heat exchange between the airstream and cold nitrogen gas, to a temperature of about –179° C. (–290° F.). At this temperature, part of the airstream is liquefied.

b. Phase Separation. In liquid oxygen plants, the partially liquefied air is passed through a phase separator before entering the rectification process. The function of the phase separator is shown in figure 38. Liquefied air and gas enter the side of the separator at a point about two-thirds of the height of the container. The heaviest liquid (crude liquid oxygen) falls to the bottom of the separator from whence it is drained. Then it goes to the hydrocarbon absorber and the rectification column. The gaseous part of the flow (primarily nitrogen) is discharged from the top of the separator.

c. Expansion Valve. The expansion valve is used to obtain a cooling effect through the vaporization of a liquid or expansion of a nonideal gas. The rate of expansion is controlled

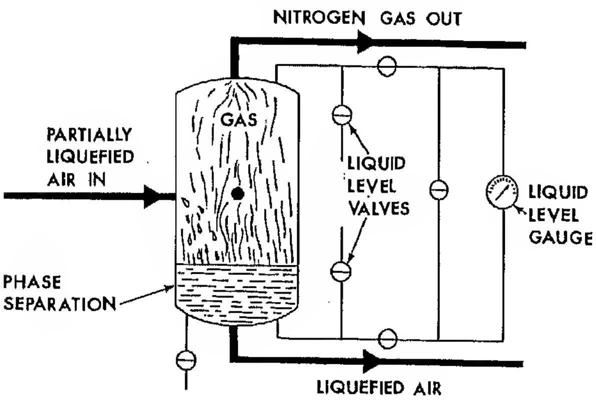


Figure 38. Cross section of a phase separator.

by use of a valve stem seating in the high-pressure inlet, increasing or restricting the opening through which the liquid or gas must pass. Controlling the rate of expansion of the stream passing through the valve regulates the drop in temperature resulting from the expansion (fig. 39).

(1) *High-pressure system.* Three expansion valves are used in this system. The first expansion valve accomplishes liquefaction of the air, the second is located in the crude liquid oxygen line to further cool the liquid before rectification, and the third is used in the liquid nitrogen line in the rectification process.

(2) *Low-pressure system.* This plant also uses three expansion valves. The first is used to cool crude liquid oxygen before rectification. The second and third valves are used to cool the nitrogen-rich air and liquid nitrogen, respectively, in the rectification process.

42. Rectification

Liquid air, partially separated into its major components (liquid oxygen and gaseous nitrogen) in the phase separator, must be processed further to insure a high degree of purity of the liquid oxygen and product. The level of purity required is on the order of 99.5 percent. Basically, the next step in the production of liquid oxygen is distillation. Rectification is simply a repeated distillation process.

a. Distillation. Distillation is the separation of the constituents of a liquid mixture by the partial vaporization of the mixture and the separate recovery of vapor and residue. This process can be illustrated by taking a liquid mixture such as alcohol and water. When such a mixture is heated under controlled conditions, the resulting vapor will contain mainly alcohol because the alcohol has the lower boiling point (fig. 40). The liquid mixture remaining will contain proportionately more and more water as the boiling action continues.

b. Process of Rectification. This is distillation carried out in such a way that the vapor rising from a still comes in contact with a con-

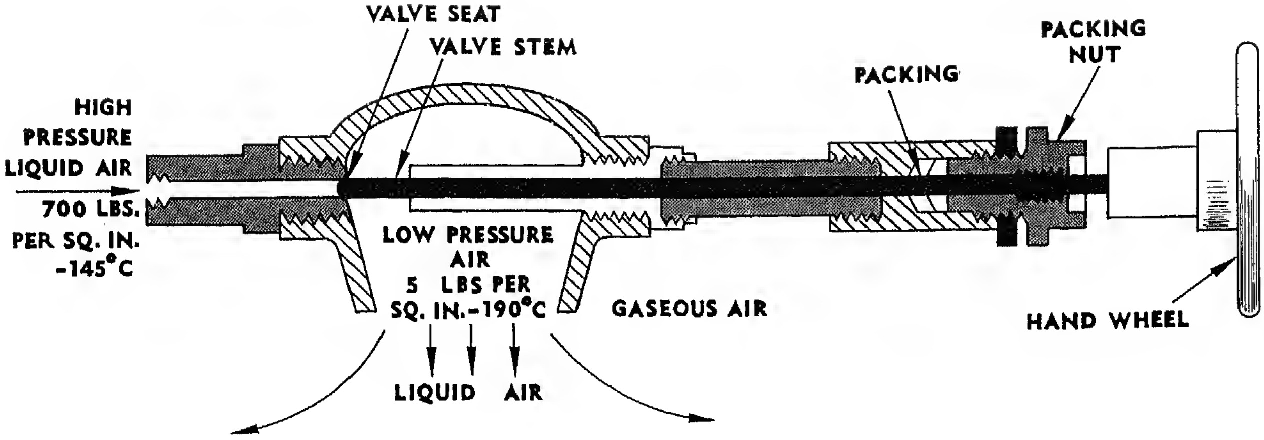


Figure 39. Cross section of expansion valve.

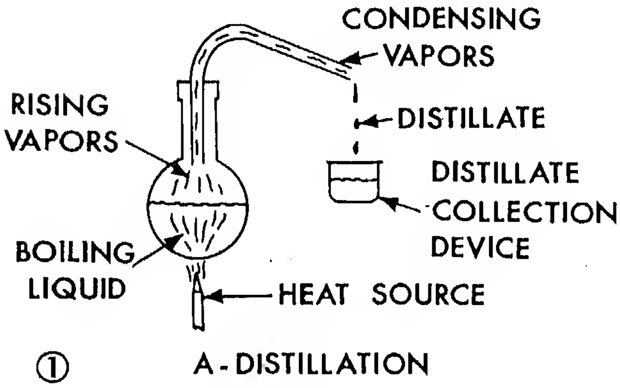


Figure 40. Distillation of alcohol.

densed portion of a vapor previously evolved from the same still. A transfer of material and an interchange of heat result from this contact, causing a larger proportion of the more volatile compounds in the vapor than could be secured with a single distillation operation using the same amount of heat. The condensed vapors, returned to accomplish this object, are termed reflux. The device which permits vapors from a still, on their way to a condenser, to flow counter-currently through to a portion of the condensate which has been returned as reflux, is called a rectifying column or tower. Figure 41 is a simplified diagram of a rectifying column.

c. Rectification of Air. In the rectification process, the gaseous and liquid nitrogen is introduced at the top of the column and the liquid travels downward in direct contact with the rising vapor. Crude liquid oxygen enters at a point one-third of the way down from the top of the column. Oxygen, being heavier and less volatile than the other constituents of the rising vapor, tends to concentrate in the liquid as it flows toward the bottom of the column, while nitrogen, being more volatile than oxygen, tends to vaporize and rise to the top of the column. The amount and purity of the product that can be withdrawn from the bottom of the column depend upon the amount of area in which the vapor-liquid contact occurs and the efficiency with which contact is accomplished (fig. 42).

d. Types of Columns. In rectification, two general types of towers or columns are used. In one the vapor-liquid contacting is done in bubble plates or trays, and in the other the tower is filled with packing to increase the wetted area avialable for continuous vapor-liquid contact.

(1) *Bubble plate column.* A bubble plate or tray may contain as many as 300 to 350 bubble caps. These caps are devices for bringing the liquid and vapor in the column into close contact for efficient scrubbing action. A bubble cap is a bell-shaped object which fits over the top of a short piece of pipe called a riser (fig. 43). The vapor rising from the tray below passes through the risers and, striking the cap, is deflected downward. The vapor escapes under the edge of the cap and bubbles up through the liquid on the tray. The more volatile nitrogen-rich gas rises and must pass

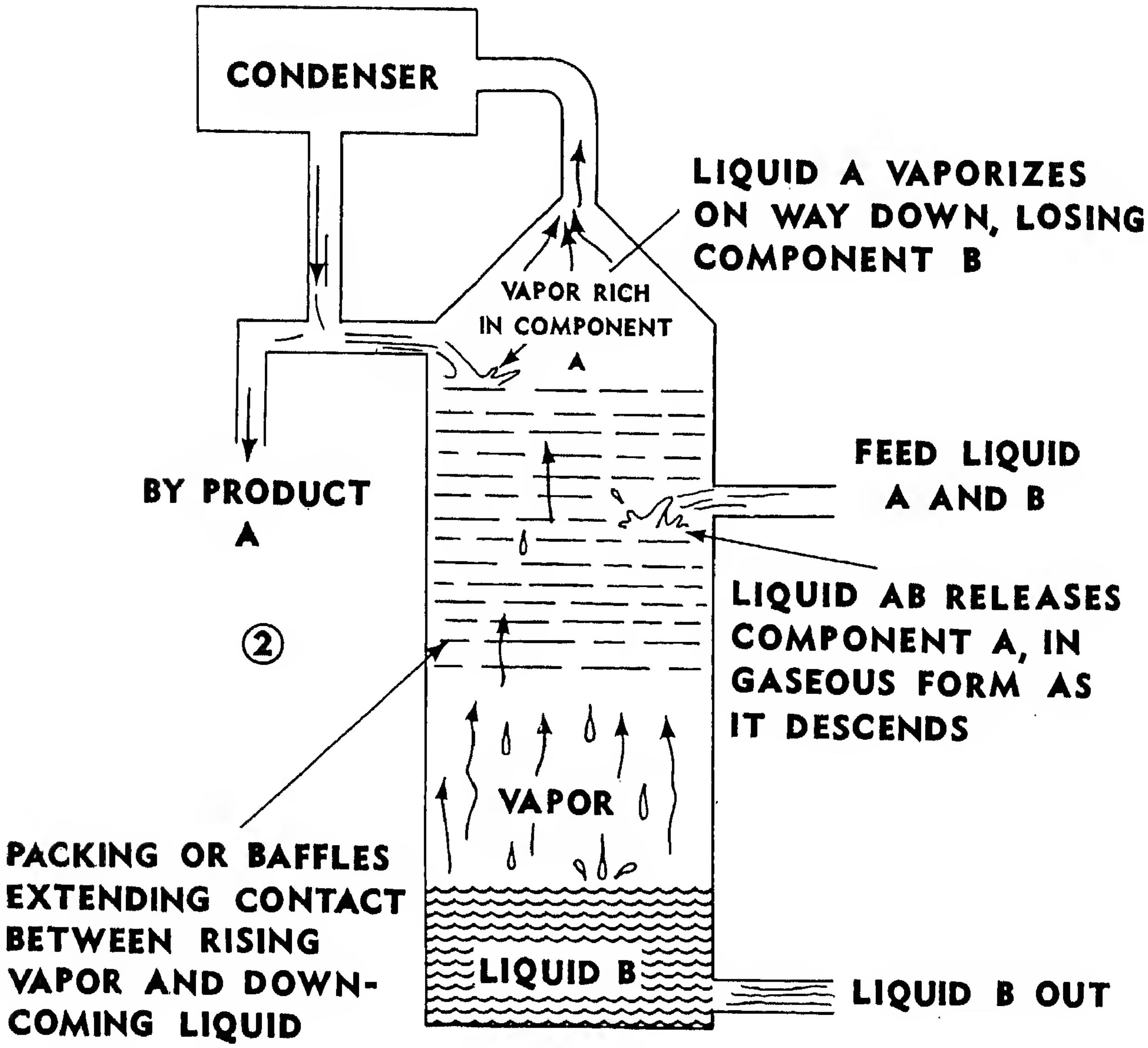


Figure 41. Rectification process.

through an oxygen-rich liquid seal covering the bubble caps. In this process gaseous oxygen in the rising vapors is condensed while liquefied nitrogen is vaporized and joins the rising vapors. Consequently, as it spills from tray to tray down the column, the liquid becomes richer in oxygen. The rising vapor becomes increasingly rich in nitrogen as it nears the top of the column.

(2) *Packed column.* The packing provides an extensive surface area which is wetted simultaneously by a stream of liquid flowing downward by force of gravity and by vapor rising from the bottom of the packed column. Figure 44 shows a sample of packing elements. The scrubbing action between fluid and vapor results in the more volatile nitrogen separating from the fluid while oxygen in the vapor condensed and enriches the fluid. The extended surface provided by the packing in the column enhances this action.

e. Columns Used in Military Plants. Column design varies to a degree between the high and

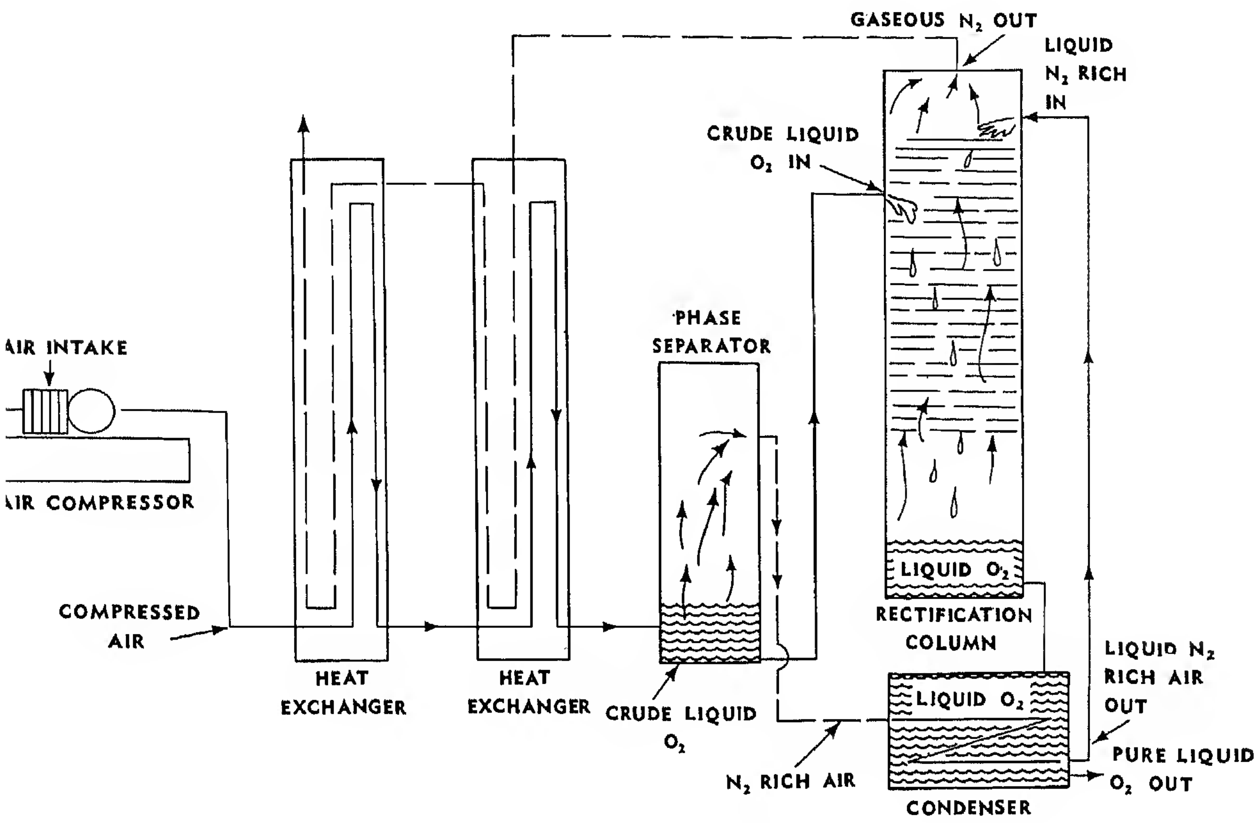


Figure 42. Air rectification progress.

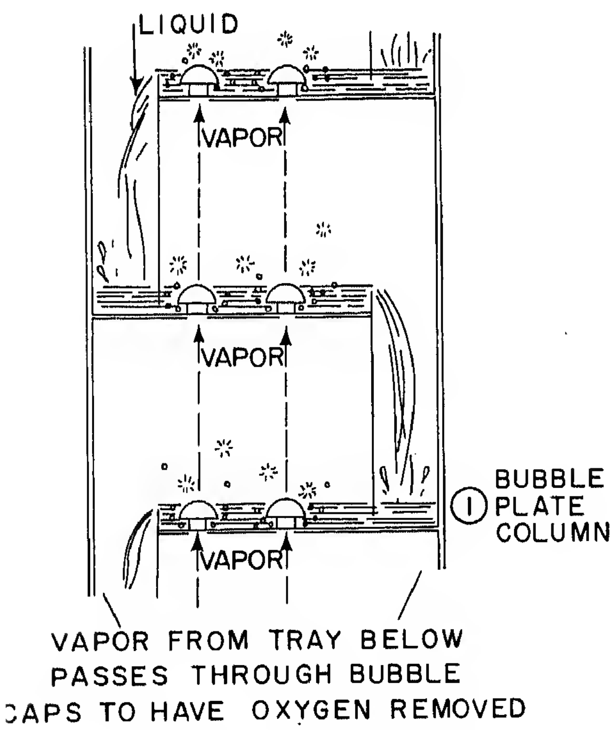


Figure 43. Bubble plate column.

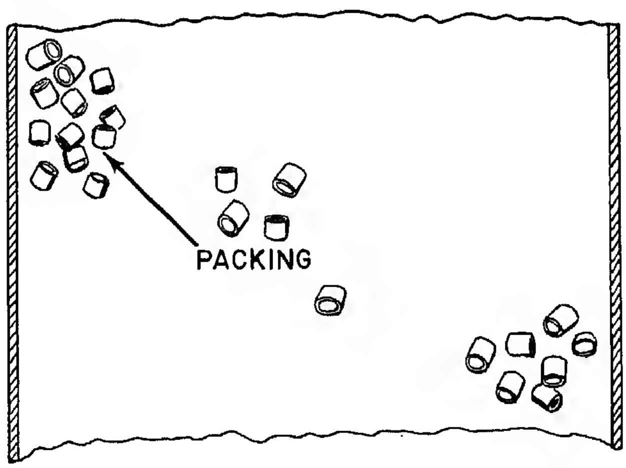


Figure 44. Sample of packing elements.

low pressure systems. The high pressure system uses a modified double distillation column consisting of a low pressure column mounted above a high pressure column and between which is a condenser (fig. 45). In the low pressure system, the column and the condenser are separate, although the functions are gen-

erally the same as in the high pressure system. Figure 46 shows the functions of the column and condensers in the low pressure system. The rectification column in both systems is of the bubble plate type.

(1) *High pressure condenser.* Nitrogen-rich air leaving the phase separator enters the high pressure colum where it is purified (95 percent nitro gen) by rectification. The high purit nitrogen then enters the high pres sure condenser where it is condense as a nitrogen-rich liquid. The tem perature reduction necessary for con

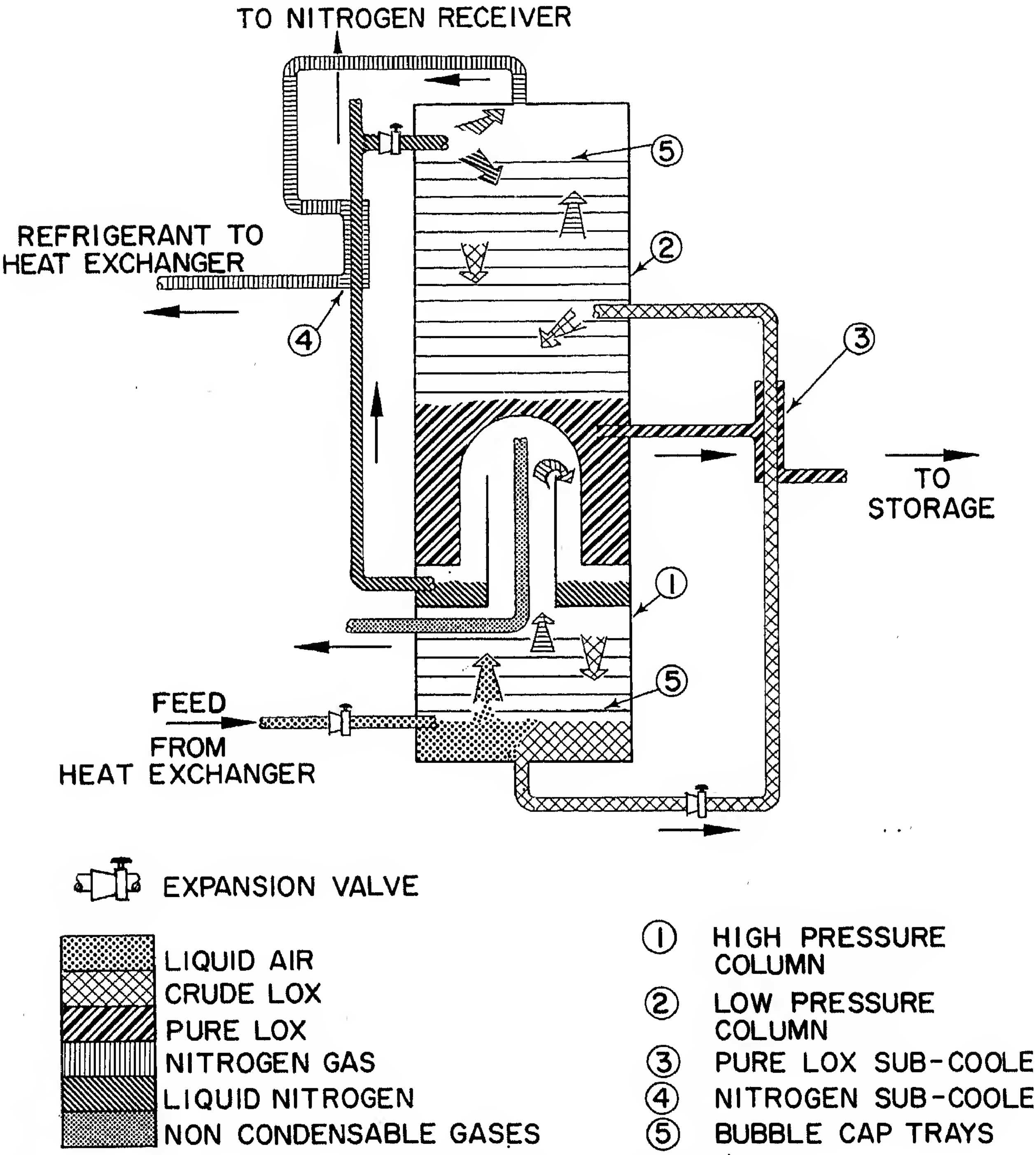


Figure 45. Modified double column.

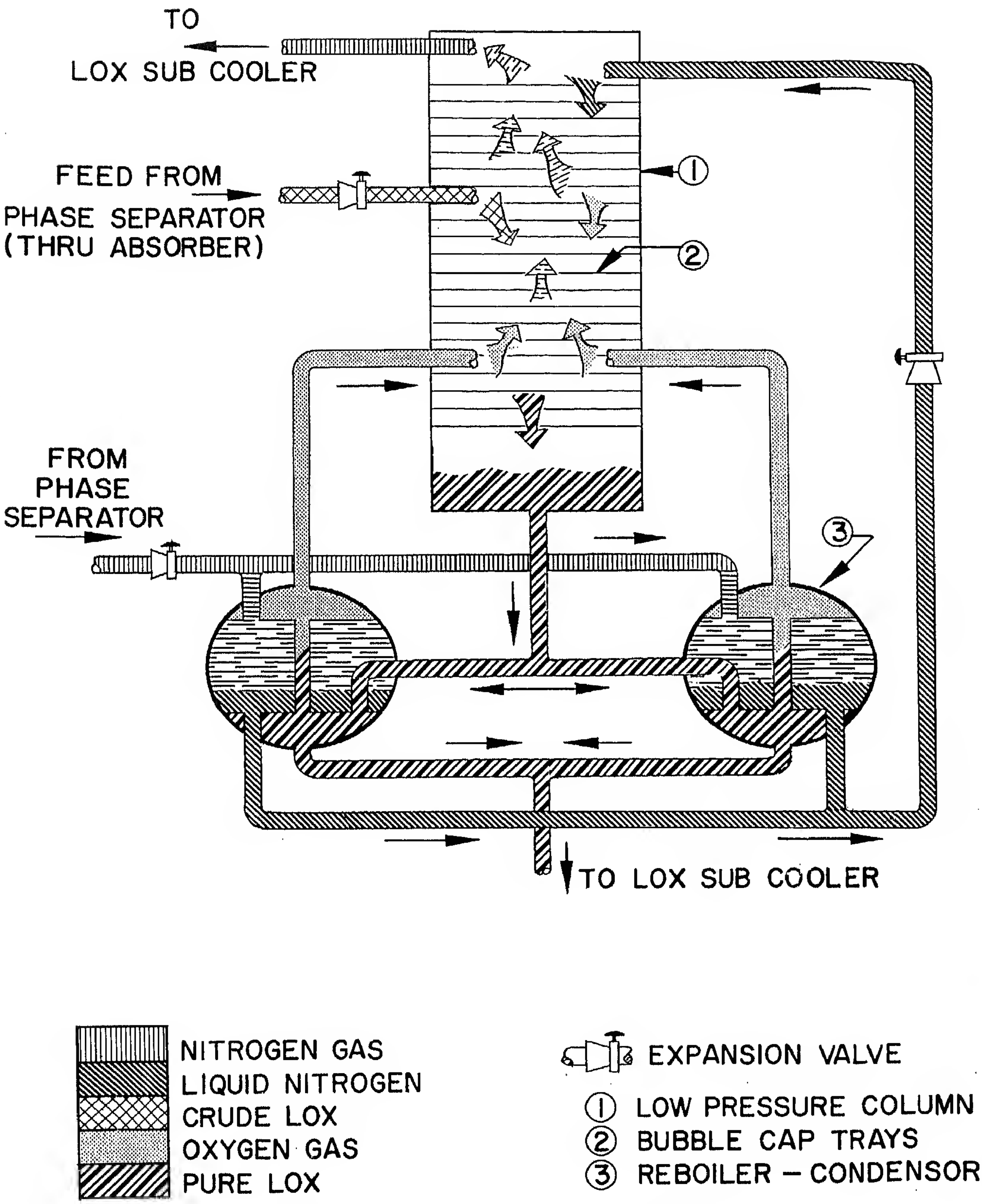


Figure 46. Low pressure column and condensers.

densation is achieved by the high purity, low temperature liquid oxygen produced in the low pressure column, which surrounds the condenser tubes and causes the nitrogen to condense by heat exchange. The resulting increase in temperature of the LOX (liquid oxygen) causes a small amount of it to boil off. The liquid nitrogen, which drops to the bottom of the condenser, is expanded through an expansion valve, and flows into the top of the low pressure column to aid in the rectification process.

(2) *Low pressure column.* The process of rectification of liquid oxygen which takes place in this column has been described in *d* above. The fluid streams entering the column to produce rectification are the liquid nitrogen produced in the condenser and crude liquid oxygen from the phase separator which has been expanded through the oxygen expansion valve and has passed through a hydrocarbon adsorber. Liquid oxygen of high purity is drawn from the reboiler condenser while gaseous nitrogen is removed at the top of the column.

f. Liquid Oxygen Subcooler. In both high and low pressure systems, the crude liquid oxygen is passed through a heat exchanger before entering the rectifying column and the pure liquid oxygen is passed through another heat exchanger upon leaving. These heat exchangers, called subcoolers, assist in the rectification process in the first instances, and in the second case, reduce the amount of liquid oxygen lost due to boiloff during the transfer to storage. Figure 47 and 48 are simplified diagram of the flow of air, nitrogen, and oxygen in the high and low pressure systems, respectively. Pressures and temperatures shown are approximate.

43. Generation of Oxygen and Nitrogen—Claude Process

As shown in paragraph 36*b*, the Claude process uses the compressed gas to perform work in an expansion engine and in accordance with the first law of thermodynamics that "work is directly proportional to the heat ex pended." The gas is cooled in the process. N attempt is made in the Claude process to lique fy the gas during the work cycle and the latte serves only to precool the gas. The final lique faction is made by the Joule-Thompson expan sion similar to that used in the Linde process Consequently the compression, purificatio (scrubbing and drying), and separation cycle of gas-generating plants using either the Lind or Claude process are essentially the same an would differ only in the methods by which the precool the high-pressure gas.

44. Plant Operating System

a. A-2 Plant. In this section the flow o oxygen, nitrogen, and caustic through a typica gas-generating plant (the A-2 plant) using th Linde process, such as shown in figure 26, i traced in greater detail.

(1) *Oxygen system.* Before pure oxyge can be charged into the cylinder mani fold, the pressure must be elevated t a value regulated by the pressur rating of the cylinder. This is don by passing the oxygen into a recipro cating pump (fig. 49) specially de signed to handle liquefied gases at lov temperatures. From the pump th oxygen is used as a refrigerant in th three-stage heat exchanger where i absorbs heat from the air. The oxy gen leaves the last section of the ex changer as a high-pressure gas at ap proximately ambient temperatur (surrounding air temperature) an passes to the charging manifold to b stored for future use.

(2) *Liquid oxygen.* The A-2 oxygen gen erating plant is also capable of pro ducing liquid oxygen in small quanti ties. This is especially useful whe there are no empty cylinders imme diately available, but it is known ther will be a heavy requirement for oxy gen. In this case it would be bot costly and time consuming to shu down the unit until cylinders wer available for filling. Consequently oxygen in the liquid form is kept i vacuum insulated storage units. Whe

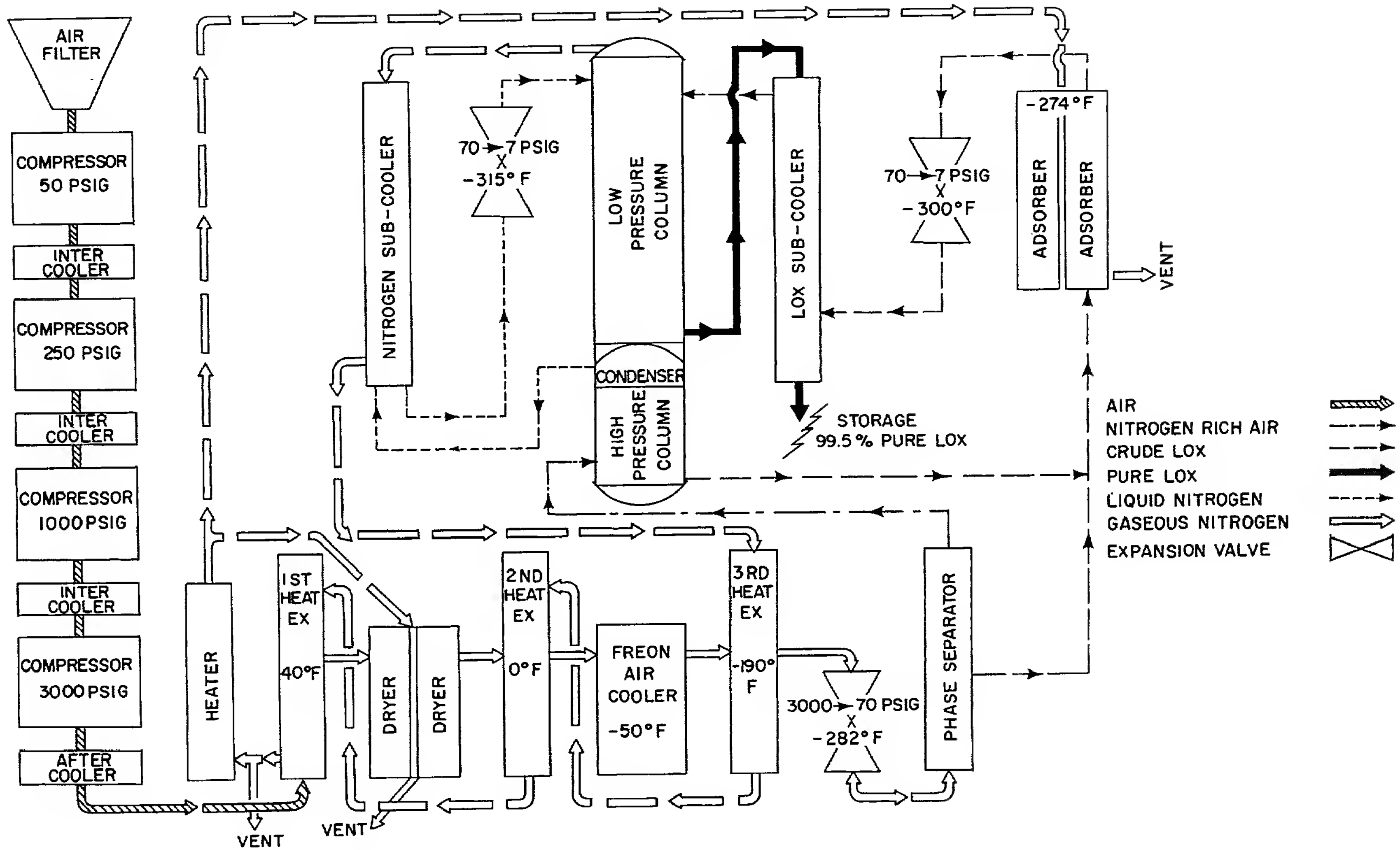


Figure 47. Typical high pressure system.

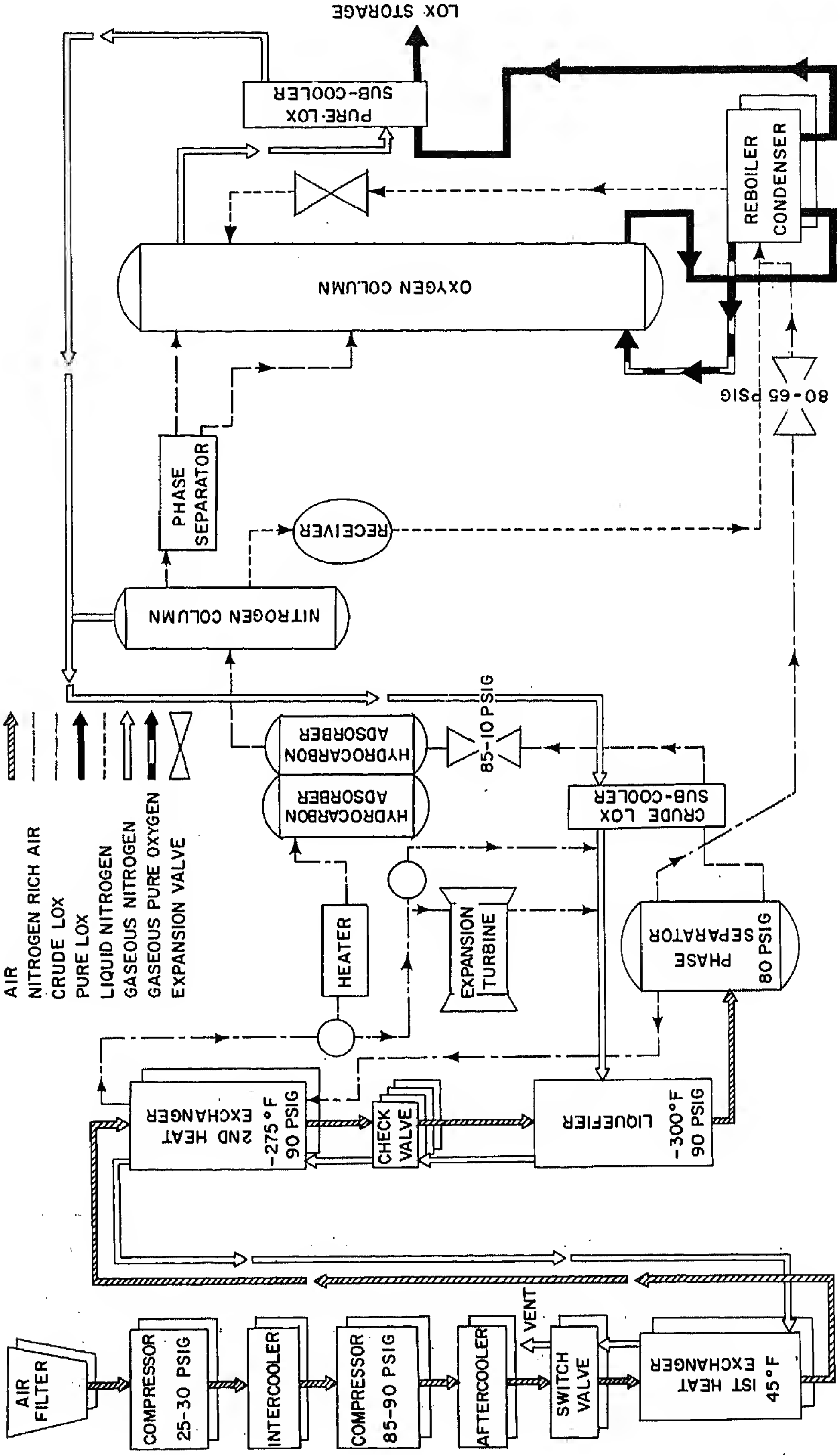


Figure 48. Typical low pressure system.

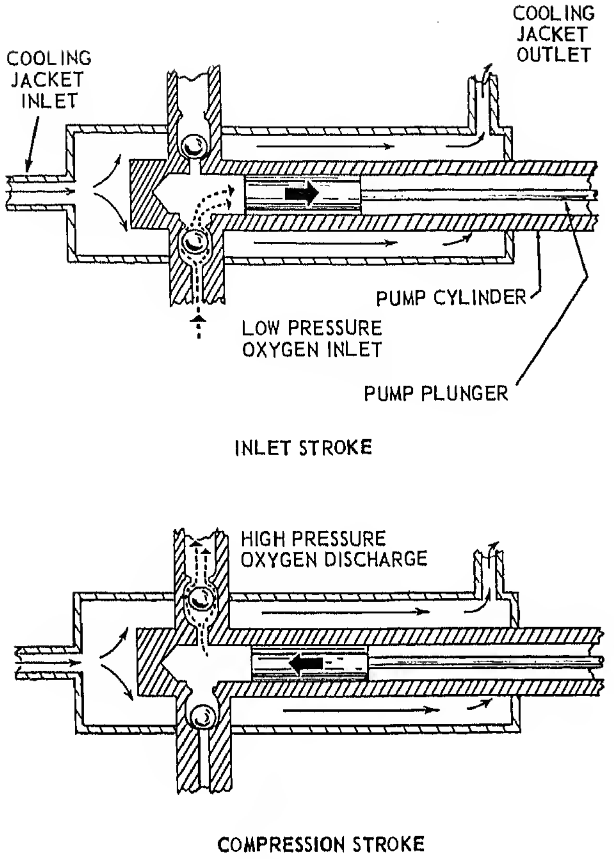


Figure 49. Cross sectional view of liquid oxygen pump.

the requirement arises, the liquid is pumped from the storage unit through an atmospheric vaporizer (where it changes to the gaseous state) to the cylinder charging manifold.

(3) *Nitrogen system.*

(*a*) *Normal operation for oxygen production.* When the A-2 plant is set up to produce oxygen, nitrogen is removed from the top of the column and is passed through the nitrogen subcooler, into the jacket of the three-stage heat exchanger. The cold nitrogen that flows around the air oxygen coils increases the rate of heat transfer between oxygen and air by maintaining the temperature differential. From the exchanger the warmed nitrogen gas is split into two streams. One flow is directed to the jacket of the oxygen-nitrogen pump where it prevents moisture from freezing on the pump plunger. The second stream is further split to direct part of the nitrogen to the silica gel dryers to regenerate the dryers, while the remainder is directed to the freon evaporative cooler and used as a cooling agent. Before entering the inoperative dryer in the regenerative cycle the nitrogen is heated by passing the nitrogen through thermostatically controlled electric heating coils so that it can absorb a larger amount of moisture. The moisture-laden nitrogen from the dryer is then vented to the atmosphere.

(*b*) *Normal operation for nitrogen production.* If the production of pure nitrogen is desired rather than oxygen, only the high-pressure distillation column is used. Instead of nitrogen being used as the reflux, it is passed to the oxygen-nitrogen pump, compressed, and charged into the cylinder manifold. Conversely, when the plant is producing nitrogen, the oxygen generated is vented to the atmosphere.

(4) *Caustic system.* In the compression cycle, a caustic solution such as $NaOH$ (sodium hydroxide) or KOH (potassium hydroxide) is used in the scrubbers to remove carbon dioxide from the air. The flow system can be followed by reference to figure 36. Water and a measured amount of caustic are added in a mixing tank and pumped into the caustic towers where the mixture is sprayed through nozzles countercurrent to the flow of incoming air. The carbon dioxide in the air is absorbed by the caustic solution, which flows out the bottom of the tower, is filtered, and again recirculated. Since the absorption capacity of the caustic is limited, the solution is periodically removed and replaced with a fresh solution.

(5) *Freon system.* The operation of the freon system is similar to any conventional mechanical refrigeration system.

b. 5-Ton and 20-Ton Plants. The 5-ton plant is essentially the same as the A-2 plant (*a* above), except that it uses hydrocarbon and CO_2 adsorbers. The A-2 plant uses the caustic scrubber system for CO_2 removal. The 20-ton plant is basically the same as the 5-ton plant, with the exception that it is a low-pressure system. Neither the 5-ton nor the 20-ton is concerned with gas production.

c. Liquid Nitrogen Production. Since liquid nitrogen is generated simultaneously with liquid oxygen, it may become the primary product, if desired. When emphasis is placed on liquid nitrogen production, the quantity of liquid oxygen produced will be greatly reduced and it will reach a very high purity.

(1) *High pressure plant.* Liquid nitrogen production in the high pressure (5-ton) plant is taken from the high pressure column as part of the same stream used as reflux in the low pressubcooler, a valve, and into a receiver in the cold box of the plant. When the receiver is full, it is transferred to an exterior storage container.

(2) *Low pressure plant.* A separate nitrogen column is used to liquefy and purify nitrogen in the low pressure (20-ton) plant. Nitrogen-rich air from the top of the phase separator is passed through an expansion valve. It flows into the nitrogen column where, in a method similar to the high pressure side of the double column (1, fig. 45), it is purified and condensed. Crude LOX from the phase separator enroute to the oxygen column is used as a reflux agent. Liquid nitrogen then flows into a receiver in the cold box and is periodically transferred to an exterior storage container.

d. Meters and Gages. In any process, the control of fluid flow, and of its temperature, pressure, and liquid level, is important. These variable determine the speed or hazard of the reaction, and when the reaction will begin. A meter or gage is placed on all process variables in a gas generating system at a predetermined point to do one or more of the following:

(1) Indicate or record, or both, the variables of temperature, flow, liquid level, or pressure.

(2) Indicate or record, or both, the variables and also control these variables should they deviate from a predetermined value.

(3) Indicate or record, or both, the variables and sound a warning should these variables deviate above or below a predetermined safe opearting value

(4) Merely signal on the rise or fall of pressure or temperature. Generally the closer these variables must be held the more complex the instrumentation system. In the generation of acetylene, for example, it is important for the safe operation of the equipment that the temperature, pressure, and liquid level in the acetylene unit be kept constant. Similarly, the control used in this unit are both more accurate and more complex than those found in other generating systems.

e. Valves. A valve controls the flow of gas, liquid, or plastic (slurry) in a line. Many types are used in the gas-generating systems described in this manual. They are divided into automatic and manual types.

(1) *Automatic.*

(*a*) *Control valves.* These are either electric- or air-operated and are actuated by a control instrument or the pressure of the flowing medium (fig. 50). Varying air pressure causes flexing of the diaphragm which works against spring tension. Flexing of the diaphragm causes the valve to open and close, allowing more or less gas or liquid to flow. When the control valves are installed in the line only to monitor the amount of flow, they are termed *straight-through valves.* They are termed *diverting-type* valves when their position in the line determines the direction of flow or the amount of fluid which will travel in each direction. The diverter type can be likened to a tee in a pipeline.

(*b*) *Relief valve (fig. 51).* This valve is a safety valve which relieves the pressure within the system when it exceeds a safe point. Its spring te

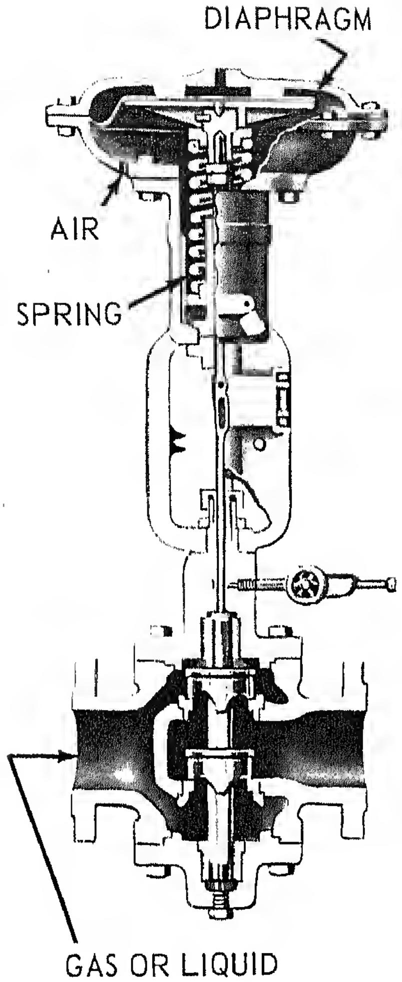


Figure 50. Diaphragm-operated control valve.

sion is preset. When the pressure exceeds this spring setting, the valve opens, vents the gas, and relieves the pressure.

(2) *Manual (figs. 52 and 53).* Manual valves are similar to those used on water or steam radiators. They vary in size and body design, but all are designed to cut off the flow of fluids by moving a gate, a plug, or other movable member across the pipe opening. In all processes, these valves serve to—

(*a*) Manually set and adjust the flow of gases, liquids, and plastics.

(*b*) Drain condensate from the lines.

(*c*) Act as sampling valves to remove representative samples of the products and test these samples for purity.

45. Summary

Oxygen and nitrogen gas-generating units will generally follow the same series of unit operations irrespective of manufacture. However, since the design of the equipment will vary among units, no attempt is made in this manual to describe the equipment in detail. The reader is referred to the maintenance manual on the particular unit involved.

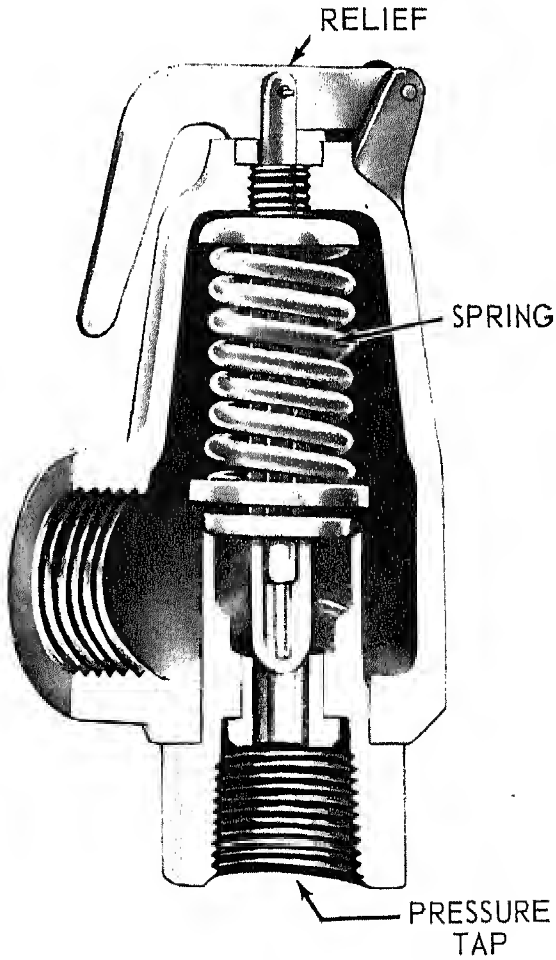


Figure 51. Pressure relief valve.

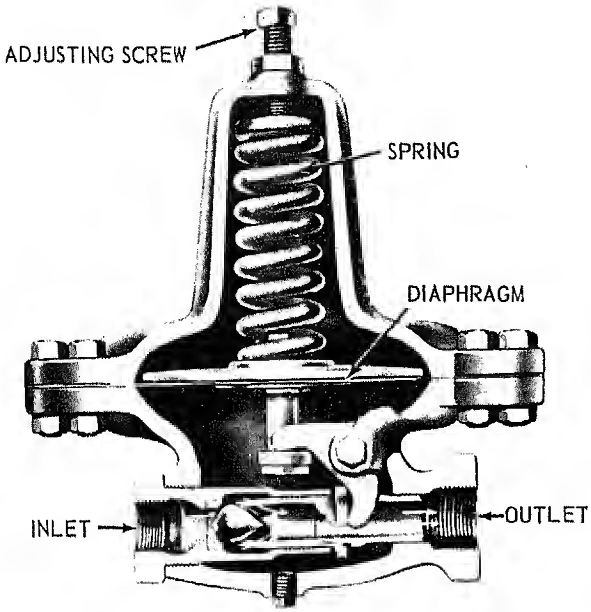


Figure 52. Gas pressure reducing valve.

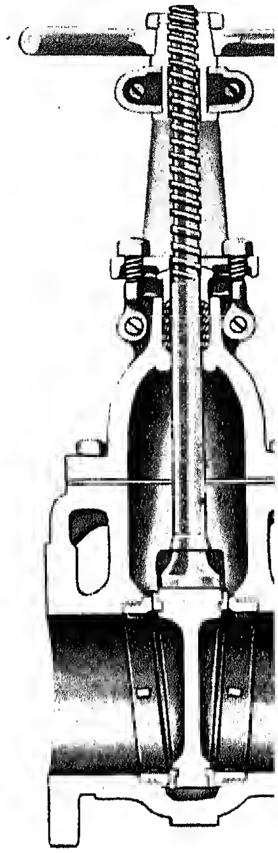


Figure 53. Hand contr

Section IV. PLANT LAYOUT

46. Introduction

Primary consideration in setting up and operatnig the plant are purity of the air source and a readily accessible and well drained location. The size of the plant itself and the large quantities of fuel and other supplies needed to operate the plant make those factors important. A well drained location insures hard standing for the equipment and prevents dangerous accumulation of oxygen and hydrocarbon in the vicinity. Because of the possibility of air contamination around large industrial areas, location of units near them should be avoided. Air containing petroleum or paint vapor, or appreciable amounts of other hydrocarbons, increases the difficulty of generating a product of high quality as well as creating an explosion or fire hazard.

47. Site Selection

Liquid oxygen and nitrogen
require an area approximatel
free of trees, underbrush, h
other combustible materials.
should be nearby. The area
at a safe distance from motor
facilities as described below.

a. Separation Distances.

(1) Keep a minimum dis
cylinder rack, powe
gas-generating unit.
gas generator setu
shown in figure 54.
all gas-generating u

(2) Locate liquid oxyge
receivers at a mini

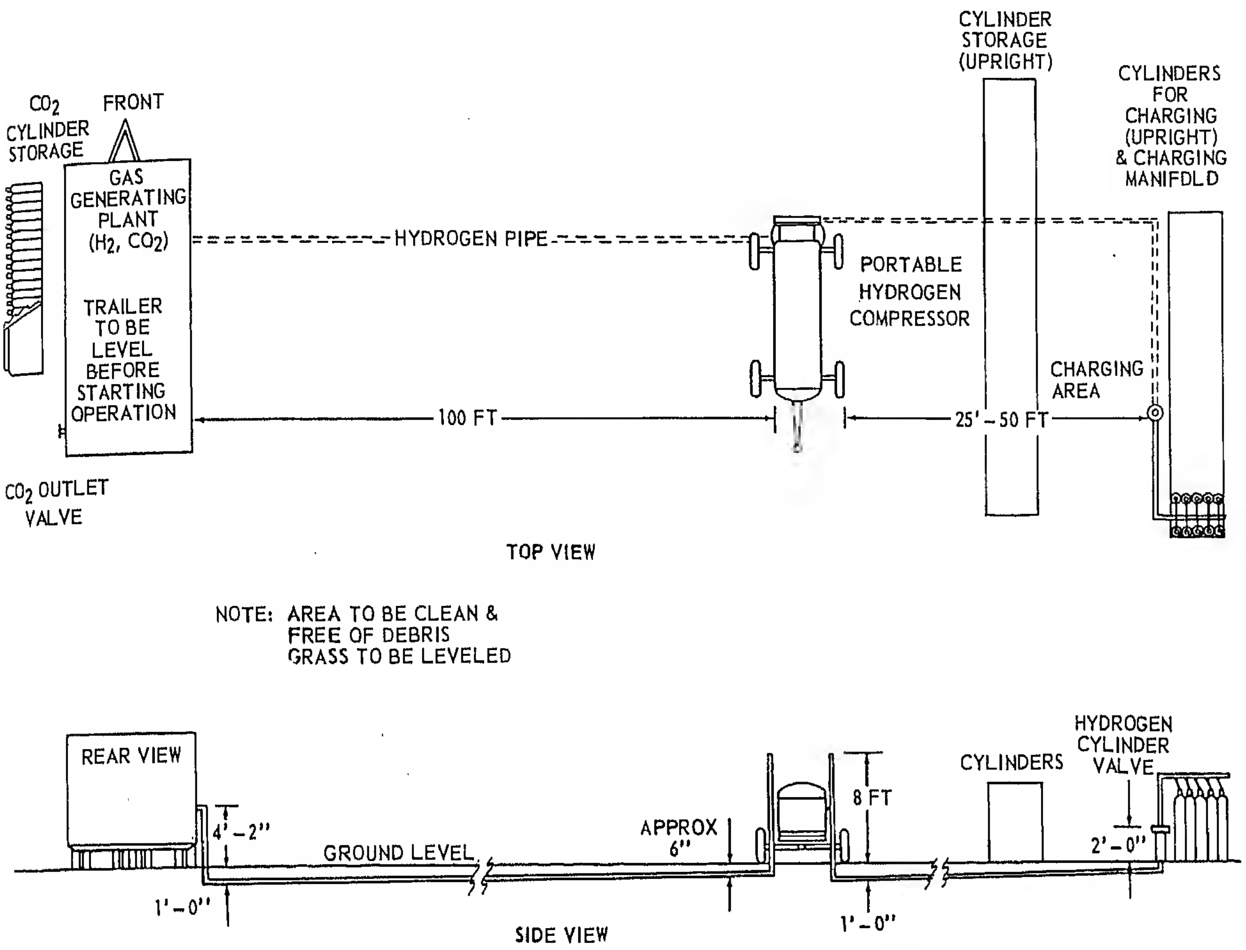


Figure 54. Representative diagram for generator arrangement in the field.

100 feet from any building, other than those structures used exclusively for activities related to such production.

(3) Do not operate liquid oxygen generators near living quarters, messhalls, and other personnel facilities. Access to areas used for either generation or storage should be restricted. Post "No Smoking" signs 100 feet from generators or supplies of liquid oxygen.

(4) Do not park vehicles loaded with gaseous or liquid oxygen within 100 feet of any building, storage yard, or other vehicles, except those used for production, storage, or transportation of oxygen. Do not place liquid oxygen in storage or on vehicles in areas where the ground is contaminated with such items as oils, other flammable liquid, sawdust, coal, charcoal, or any highly combustible material.

(5) Do not dump liquid oxygen near the oxygen generator, nor near living quarters, shops, repair yards, and other general sources of ignition. At the point selected for dumping liquid oxygen, terrain conditions should minimize the possibility of the concentration of gaseous oxygen in the intake air for internal combustion engines. At the low temperature conversion from the liquid state, gaseous oxygen is heavier than air and will tend to flow downgrade unless carried in another direction by the wind. One cubic foot of liquid oxygen will produce about 860 cubic feet of gaseous oxygen, thus creating a hazardous oxygen-

enriched atmosphere over a wide area. Protect discharge point from strong winds blowing toward the generator or other equipment. Whenever liquid oxygen in the generator storage container is to be dumped, it should be piped from its container to the disposal area. Use nonferrous pipe and fittings. Under normal operating conditions, pressure in the pipe woud not be a problem, but there is a possiblity that freezing could block the pipe. The discharge line between the plant and dump should not contain two valves, because accidental closing of both may explode the line. Locate the discharge end of the pipe where the liquid oxygen being dumped is discharged into an open metal container (steel, copper, or aluminum), a sand or gravel pit, a pit with a gravel bottom, or a natural watercourse with a sand or gravel bottom. In all cases, it is advisable for the surface of the dumping area to slope away from the point of liquid oxygen discharge, and for the end of the discharge pipe to be high enough above the dumping bed to insure that it will not be obstructed. Never dump liquid oxygen on dead vegetation, leaves, or decayed material often found ni wooded areas. Clear dumping pits down to the subsoil. Tree roots in dumping pits, or exposed on the bank of a watercourse, are not hazardous.

(6) Forested areas are serious fire hazards, particularly in dry weather. Wooded areas restrict air movement and reduce the rate of dissipation of dumped liquid oxygen. Unless vegetation is of utmost importance in camouflage, do not set up a liquid oxygen plant closer than 100 feet from a forested area.

b. Siting in Industrial Area. If is necessary to operate liquid oxygen equipment near an industrial area, select a site upwind (in the direction of the prevailing wind) from industrial plants or other sources of contamination. Any major combustion within 500 yards of the plant is likely to change the atmospheric environm and should be avoided. Combustible materia such as acetylene, that have low solubilities liquid oxygen are particularly dangerous si they concentrate or build up within the pla Acetylene, either from ambient air supply from breakdown of lubricating oil in a hot co pressor, has been known to have caused exp sions in oxygen generation equipment.

48. Site Preparation

Place liquid oxygen generators and equ ment for charging containers on a clean, le area. A concrete or sand and gravel hardsta is recommended for the area under and adjac to mobile generators. Do not use oil or asph surfaces. The joints for concrete hardsta should be made of noncombustible LOX-co patible material. Timbers may be used to s port van jacks over a clean earth surface wh it is impossible to provide concrete or sand a gravel. Timber is combustible, but it is considered an explosive hazard if liquid oxy contacts smooth-surface timbers. Where slope of the ground might allow spilled fuel oil from the air source semitrailer or fuel system to flow toward the column semitrai dikes or trenches should be provided to al for safe runoff. Where feasible, place drip p under trailers to catch spilled fuel oil or lu cant. In place of drip pans, use noncombu ble, absorbent materials or clean, loose eart least 1 inch thick, but remove this material replace it if it becomes oil soaked.

49. Operating Notes

Safe, efficient operation of liquid oxy plants requires the operator to be familiar v the information presented in this manual with the operating procedures prescribed other technical manuals appropriate to spe equipment. Operating procedures and pre tions are generally applicable to liquid oxy equipment now in use. Detailed informa will be found in TM 38–750 and in TM 5–36 204–10.

50. Oxygen and Nitrogen Purity Tests

a. Oxygen Purity Test.

(1) Dirt and impurities in liquid oxy

are two of the most probable causes of equipment malfunction. Avoid contaminating the lines and fittings with oil and dirt. Purity standards for handling and testing should be according to Federal Specifications BB–0–925. Oxygen purity can be measured by reacting the oxygen product gas in a test apparatus solution using a solution of 1 part of 28 percent ammonium hydroxide solution and 1 part distilled water saturated with ammonium chloride. Figure 55 shows the test set with the nomenclature of its parts.

(2) Hazardous concentrations of acetylene are not expected where the air supply is relatively pure, the hydrocarbon filters are properly maintained, and the plant is drained and defrosted once a week. Under other conditions, samples of liquid oxygen should be analyzed periodically for acetylene concentration. This is generally the most important test, and makes use of the Ilsovay test equipment. Total hydrocarbon concentrations in liquid are important, but tests can only be made with complicated equipment not available in Army supply channels. If the plant is operated in open country and free of elements listed in paragraph 47*a*, other hydrocarbons such as methane, ethane, or ethylene are either not present or of insufficient concentration to be considered.

b. Oxygen Test Procedure. For detailed information on checking the condition of oxygen generating and testing the purity of oxygen, see TM 5–3655–204–10.

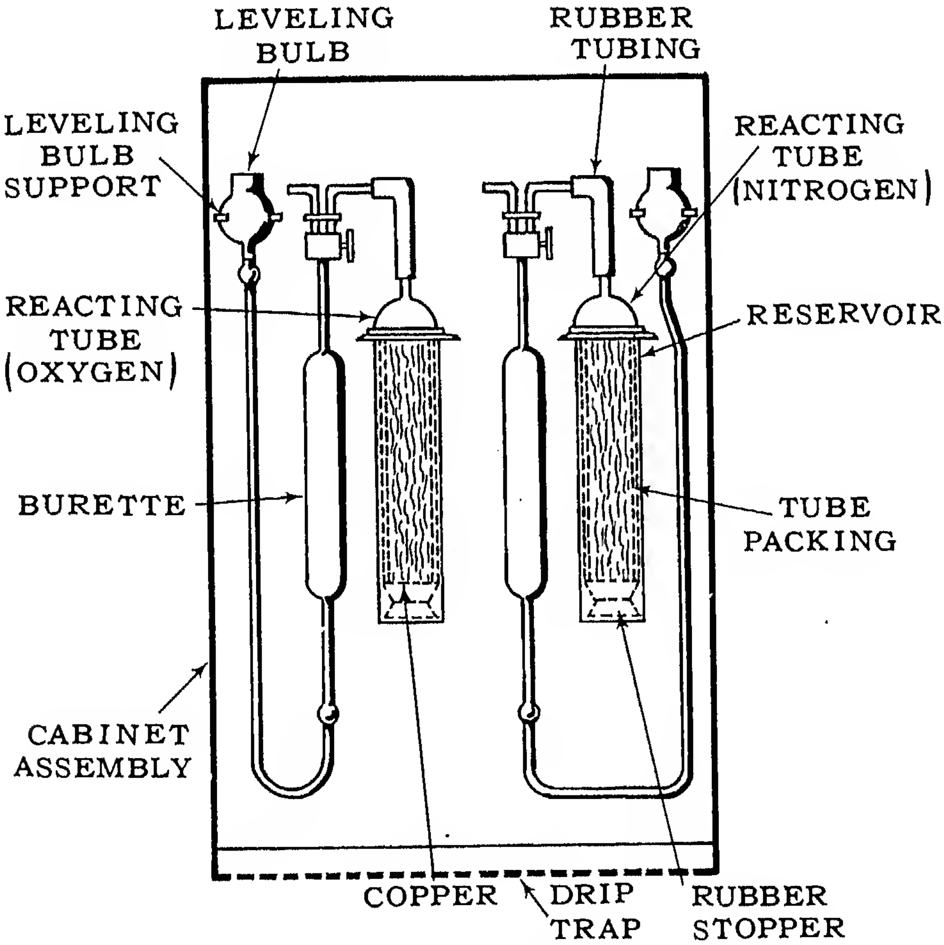


Figure 55. Oxygen-nitrogen purity test equipment.

c. Nitrogen Purity Test. The nitrogen test set is similar in design and principle to the oxygen test set. A pyrogallol solution is used for the test and the reacting tube is filled with small glass tubes to provide a larger contact surface (fig. 55).

d. Nitrogen Test Procedure. For detailed information on checking the condition of nitrogen generating equipment and testing the purity of nitrogen, see TM 5-3655-204-10.

Section V. SAFETY AND PROTECTIVE MEASURES

51. Safety Precautions

This section will cover the specific safety precautions associated with the generation of oxygen and nitrogen. The general precautions for these matrials stored in cylinders are covered in section V, chapter 5. The refrigerating system in the oxygen and nitrogen plant uses freon as the refrigerant because of its nontoxic and nonflammable characteristics. The specific safety precautions covering all types of refrigerants (ammonia, methyl chloride, and sulfur dioxide) are not covered in this manual but can be found in AR 700-8120-1. Other information pertaining to safety measures will be found in paragraphs 47 through 49 above.

a. Oxygen.

(1) Never permit oil, grease, or other readily combustible substances to come in contact with oxygen cylinders, valves, regulators, gages, and fittings.

(2) Never lubricate oxygen valves, regulators, gages, or fittings. Do not handle oxygen cylinders or apparatus with oily hands or gloves. The uncontrolled contact of oil and oxygen under these conditions may cause an explosion.

(3) Never use oxygen from a cylinder without reducing the pressure through a suitable regulator.

(4) Use only approved oxygen regulators, hose, and other appliances.

(5) Never use oxygen cylinders for other than oxygen service.

(6) Never use oxygen as a substitute for compressed air in pneumatic tools, for building up pressure in oil reservoirs, for paint spraying, for blowing out pipelines, or for similiar purposes for which compressed air is normally used. The mixture of oil with oxygen can result in an explosion.

(7) Never use compressed oxygen or any other compressed gas for cooling the body or for blowing dust from clothing.

(8) For cleaning purposes, use trichloroethane (Fed. Spec. O-T-620a) or any drycleaning agent of similar quality and characteristics. Do not use carbon tetrachloride, gasoline, or other organic solvents. The area where cleaning operations take place must be well ventilated because the fumes of trichloroethane are poisonous. Personnel should keep on the windward side. Gas masks are effective only when the work is done in the open. When cleaning indoors, use a standard breath apparatus such as the M15.

b. Nitrogen.

(1) Nitrogen is an inert gas and therefore creates no special problem of handling. However, in certain areas, such as the interiors of storage vessels that do not have sufficient ventilation, a high concentration of nitrogen can lead to the danger of suffocation.

(2) Nitrogen cannot be used for inert-gas shielded welding because the high temperature required can cause nitrogen to combine with other substances.

c. Liquid Oxygen. The properties of liquid oxygen make it dangerous if improperly handled, and moderately safe if properly handled. The fire hazard associated with liquid oxygen is not the burning of the oxygen, but rather the ability of the oxygen to support combustion. Ordinarily, combustible materials will catch fire much easier in an oxygen-rich atmosphere.

Follow the safety and protective measures listed below:

(1) *In plant facilities.*

(*a*) Install automatic showers portable or fixed, in each plant site.

(*b*) Install an adequate number of fire hydrants at each plant site, equipped with sufficient hose and fog nozzle. If there is no piped water supply, station at each plant site a fire truck or water storage container fitted with pumps, hose, and fog nozzle.

(*c*) Locate a fire alarm at a convenient point within the plant site.

(*d*) Place a medical aid station within the plant site, and equip it to treat first aid type injuries.

(2) *Pre-start Inspection.*

(*a*) Insure that equipment is grounded and positioned properly with respect to wind direction.

(*b*) Remove combustibles from plant area.

(*c*) Make visual check of equipment to determine safe operating condition.

(*d*) Inspect pop-valves to determine condition and seals; replace damaged valves.

(*e*) Inspect interconnecting air lines and hoses to determine condition and tightness of connections.

(*f*) Check that all valves are properly set and that an outlet is provided for any excessive pressure condition.

(3) *During-operation inspection.*

(*a*) Insure that process air is flowing through the 5-ton plant before the freon system is in operation.

(*b*) Insure that the seal air and lube oil to the 20-ton expansion turbine is in operation before starting the turbine.

(*c*) Observe the condition of the safety valves for frost, dirt, rust, and loose parts.

(*d*) Do not break lines without first draining or relieving pressure.

(*e*) Do not vent pressures in direction of personnel.

(*f*) Maintain a high degree of cleanliness at all times to prevent accidents. Emphasize that no oil will be permitted in areas where liquid oxygen is present.

(*g*) Make sure that oily rags are removed from plant area and that personal clothing is clean.

(*h*) Prohibit smoking.

(*i*) Insure that all transfer and draining lines are tight.

(*j*) Be continually alert to operating pressures and temperatures.

(*k*) Maintain an accurate log sheet to record plant operation.

(4) *Shutdown operations.*

(*a*) Do not dispose of liquid at a rate which cannot readily vaporize or which increases the oxygen content of the atmosphere surrounding the plant.

(*b*) Be sure that the area into which liquid oxygen is drained is free of combustibles and hydrocarbons.

(5) *Preparation for movements.*

(*a*) Make certain that all liquid has been drained and that the plant is warm.

(*b*) Close outlets to atmosphere to prevent dirt from entering any part of the system.

(6) *Maintenance precautions.*

(*a*) Make sure that tools and clothing, particularly gloves, are free of oil, carbon, and dirt.

(*b*) Use only authorized cleaning compounds and materials.

(*c*) Insure that materials and repair parts are suitable for use with the temperatures and pressures of the service to which they are applied.

(*d*) Use only the prescribed threading compounds.

(*e*) Take extreme caution to make proper unit replacements.

(*f*) Tag the disassembled parts to provide accurate reassembling.

(*g*) Use only approved lubricants to service the equipment.

(*h*) Observe extreme caution when welding; insure that liquid oxygen equipment is free of oxygen vapors before welding.

(7) *Emergency action.* In the event of a liquid oxygen injury or an oxygen-fed fire, immediate action is necessary to give medical aid to personnel and to extinguish the fire:

(*a*) In cases where individuals have been splashed with liquid oxygen or have parts of their bodies submerged in it, immediately wash the affected area with fresh water. Remove such persons from the area to to receive further treatment from a medical officer. Report personnel injuries to proper authorities.

(*b*) Liquid oxygen fires present a problem because the fire is provided with a plentiful amount of oxygen in highly concentrated form. Because removal of the oxygen is out of the question and cooling below the ignition point is difficult, the fire is restricted with large quantities of water. Water has the added advantage of flusing the area and removing the liquid oxygen, as well as cooling the combustible material. Liquids and solids in general ignite at much lower temperatures in a high oxygen atmosphere. Plenty of water (solid stream of fog of high or low velocity) is the only effective means of fighting liquid oxygen fires. Other permissible fire fighting materials are chemical (powder) foam and carbon dioxide or another inert gas. Do *not* use the soda-acid extinguisher, mechancial (liquid) foam, methyl bromide, nor carbon tetrachloride.

d. Tips and Techniques.

(1) Do not bring hot objects into the plant.

(2) Use only sparkless tools.

(3) Know location of, and how to use, approved fire extinguishers.

(4) Always be properly dressed.

(5) Keep yourself and your working areas clean.

e. Freon.

(1) *Introduction.* The term "freon" covers a group of refrigerants which are available commercially under number designations: freon 11, 12, 22, and 114. For example, freon 12, the most common, is chemically known as dichlorodifluoromethane, has the formula CCl_2F_2, and is composed of carbon, chlorine, and flourine. The freon refrigerants are nonflammable, nontoxic, nonexplosive. However, in the presence of fire or red hot metal, they decompose to form phosgene which is extremely toxic.

(2) *Safety rules for freon.* Freon cylinders are subject to the same handling and refilling rules that are given for ammonia cylinders except that standard freon cylinders are of 5-, 25-, and 150-pound capacities. Avoid overcharging the cylinders. Insure the cylinders are empty before using by opening their valves and venting them out-of-doors. Carefully weigh the cylinders, and repeat this weighing while filling; if any cylinder is accidentally overfilled, discharge the excess gas slowly.

(*a*) Men who service freon refrigeration systems should wear safety goggles to avoid the chance of liquid freon coming in contact with their eyes and causing injury because of the freezing effects of the liquid.

(*b*) Should a man be overcome by lack of oxygen in a working space because of a high concentration of freon gas, he should be treated as in a case of suffocation; artificial respiration should be started immediately.

52. Fire Fighting

When working with gas-generation equipment, Army personnel will use numerous materials which are fire hazards. Since the possibility of fire and explosion is always present in this type of work, it is necessary for all personnel in or around a gas-generating station to

understand fundamental fire fighting measures. Normally various types of fire extinguishers are located in a gas plant or throughout the generating area to prevent small fires from spreading and reaching major proportions. The successful employment of fire extinguishers, however, depend on their quick use and the skill of the user. Thus, it is imperative that all personnel associated with the generation of compressed gases becomes familiar with the location and operation of the fire extinguishers in the area, and that standard operating procedure be established for periodic inspection of extinguishers. Before studying the types and proper operation of portable fire extinguishers, however, gas-generating personnel should review or become familiar with both the classification of fires and the flammability and ignition point of materials with which they will come in contact.

a. Classification of Fires. Accepted practice usually classifies fires according to the fuel involved and the fire-fighting procedures which must be used to extinguish them. (For liquid oxygen's hazards see paragraphs 51 and 53.)

(1) *Class A.* Class A fires are those in ordinary combustible materials where the cooling or quenching effect of water or solutions containing water is the extinguishing factor. Examples of combustible materials in this class are paper and wood.

(2) *Class B.* Class B fires are those in flammable liquids and greases. Air exclusion or blanketing are essential in extinguishing these fires. Examples of class B fires involve all types of petroleum products.

(3) *Class C.* Class C fires are those in electrical equipment where a nonconducting extinguishing agent is of first importance. Class C fires are primarily electrical fires in motors, transformers, and the like.

b. Flammability of Common Materials. See tables V and VI.

c. Types of Extinguishers. Fire extinguishers operate on two basic principles: cooling or quenching burning material below the ignition temperature (water type), and excluding oxygen with a blanket of foam or gas (foam, carbon tetrachloride, and carbon dioxide extinguisher). The following types are used by the Army.

(1) *Water-pump tanks.* Water-pump tanks, issued in 2½-, 4-, and 5-gallon sizes, have a fixed pump which can throw a stream of water 30 to 40 feet (fig. 56). Since their extinguishing agent is water, they are best suited for class A fires. To receive the maximum effect, use a series of short, rapid strokes of the pump to provide a continuous stream. Keep the nozzle as close as possible to the fire and direct the stream of water at the base of the fire instead of at the smoke and flame.

Table V. Flammability Limits and Ignition Temperatures of Liquids

Liquid	Limit of flammability Percent by volume	Ignition temperature
Gasoline, 73 octane	1.50 to 7.40	300°C. (570°F.)
Gasoline, 92 octane	1.50 to 7.60	390°C. (734°F.)
Gasoline, 100 octane	1.45 to 7.50	430°C. (804°F.)
Fuel oil No. 1	----------	38°C. (100°F.)
Fuel oil No. 2	----------	38°C. (100°F.)
Acetone	2.55 to 3.00	700°C. (1292°F.)
Methanol	6.70 to 7.30	555°C. (1031°F.)*
Monoethanolamine	----------	----------
Freon	None	None
Caustic solution	None	None

* In oxygen.

Table VI. Flammability and Explosive Range of Gases

Gas	Flammable	Flammable range with air (%)
Acetylene	Yes	2.5 to 80.0
Ammonia	Yes	16.0 to 26.0
Butane	Yes	1.6 to 6.5
Carbon dioxide	No	None
Chlorine	No	None
Helium	No	None
Hydrogen	Yes	4.1 to 75.0
Methyl chloride	Yes	8.3 to 19.7
Nitrogen	No	None
Oxygen	No	None
Propane	Yes	2.1 to 7.5
Sulfur dioxide	No	None

(2) *Soda-acid extinguishers.* Soda-acid extinguishers (fig. 57) are fundamentally water-type extinguishers using 2½ gallons of water mixed with 1½ pounds of bicarbonate of soda. When the extinguisher is inverted, a

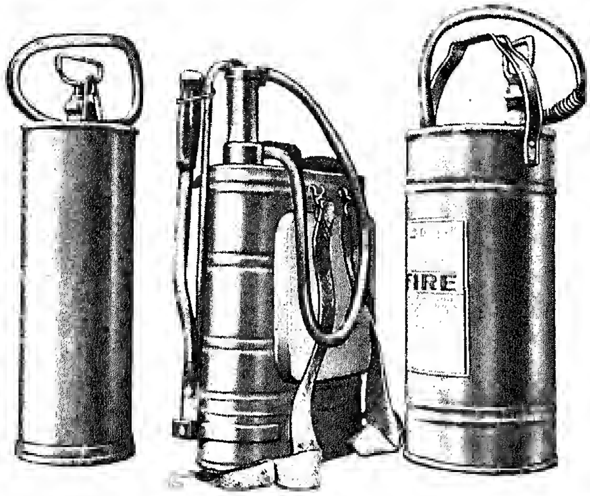


Figure 56. Water-pump tanks.

Figure 57. Soda-acid type extinguisher.

suspended bottle containing 4 ounces of sulfuric acid empties into the soda solution, producing carbon dioxide gas under pressure which expels water for a distance of 30 to 40 feet. The carbon dioxide has little or no extinguishing value. The soda-acid extinguisher is best suited for a class A fire. Carry the soda-acid extinguisher to the fire in upright position and invert only when ready to use, because the fluid flows continuously until gone or until the extinguisher is placed upright again. As with the water pump type, direct the stream so the solution cools and quenches burning material at the base of the fire. Protect against freezing in colder climates by placing the extinguisher in a heated building or in a closed box where a heating device has been installed. Chemicals cannot be added to lower the freezing point because such chemicals destroy the pressure-building reaction between soda and acid.

(3) *Foam extinguishers.* Foam type extinguishers are used for class B fires involving flammable liquids (fig. 58). The foam type is also adaptable to a class A fire. When used on a class B fire, it acts as a blanket by floating on the surface and isolating the fuel from the air. Fluids such as alcohol and acetone require a special foam because they act as a solvent and destroy standard foam bubbles. Foam extinguishers are similar to the soda-acid extinguisher. However, because the material discharged is a foamy mass, a larger nozzle is needed. The extinguisher has an outer chamber holding a mixture of sodium bicarbonate and several quarts of water, and an inner chamber holding a solution of alumina sulfate in 2¼ pints of water. To these chemicals a foam stabilizer is added. Apply foam to a flaming liquid surface as gently as possible. This can be done either by hitting against the walls of the container, thus allowing the foam to cover the surface without splashing, or by applying foam at the extreme range of the stream, so it reaches the flaming surface with most of its propelling force gone. Where the burning fluid is spilled on a flat surface, direct the stream against the ground near the fire so it rolls or flows over the area involved. Where possible, help the foam blanket spread by moving around the burning fluid.

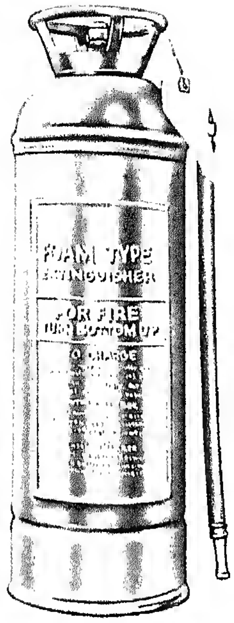


Figure 58. Foam type extinguisher.

(4) *Carbon dioxide extinguishers.* Carbon dioxide extinguishes fires by displacing air or diluting its oxygen content and is best suited for class B fires (fig. 59). In operation, the liquid carbon dioxide under pressure in the tank is released to the atmosphere where it changes to a vapor, expanding in a ratio of approximately 500-to-1 at a temperature discharge of −79° C. (−110° F.). Though this temperature is quite low, the heat-absorbing capacity of carbon dioxide is still limited, being only about 10 percent as efficient as water. The relatively high internal pressure generated by carbon dioxide when subjected to comparatively normal temperature changes limits the location of such extinguishers. For example, at −18° C. (−0° F.) the internal pressure would be 285 pounds per square inch. At 38° C. (100° F.) the cylinder pressure would be 1,450 pounds per square inch. Therefore, carbon dioxide extinguishers should not be installed near heating equipment, and must be protected from the direct sun rays during hot weather. This high-pressure characteristic requires containers of heavy materials. For example, an empty 15-pound extinguisher weighs about 35 pounds. In use, direct the discharge at the base of the fire, because carbon dioxide gas extinguishes fire by air exclusion. Move the discharge horn of the extinguisher at a moderate rate to form a bank of inert vapor between the blazing and extinguished portions of the fire. Rapid movement dissipates the vapor as it is discharged; too slow movement may discharge more than is needed at one point. Since it works by excluding air this type of extinguisher is most effective in a confined space where the gas can blanket the fire. In this case, personnel must use caution to avoid breathing too much of the gases produced. Carbon dioxide extinguishes fire by depleting the oxygen supply to below 15 percent, which is also the critical concentration for sustaining human life. The chief hazard to personnel using this type of extinguisher is suffocation. The freezing effect of the snow is not serious unless exposed portions of the skin are directly sprayed.

(5) *Carbon tetrachloride extinguishers.* Carbon tetrachloride extinguishers (fig. 60) use a special extinguishing compound having a carbon tetrachloride base with certain ingredients added to lower the freezing point and resist corrosion. The Army uses pump-operated and stored-pressure types. The 1-quart size is of two types, one pumping out the liquid directly and the other pumping in air to expel the liquid. Carbon tetrachloride is very volatile, evaporating to form an inert gas heavier than air. This gas extinguishes fire by air exclusion or dilution. The liquid is only about 10 percent as effective as water for cooling or quenching. Since carbon tetrachloride is a nonconductor of electricity, this extinguisher is used

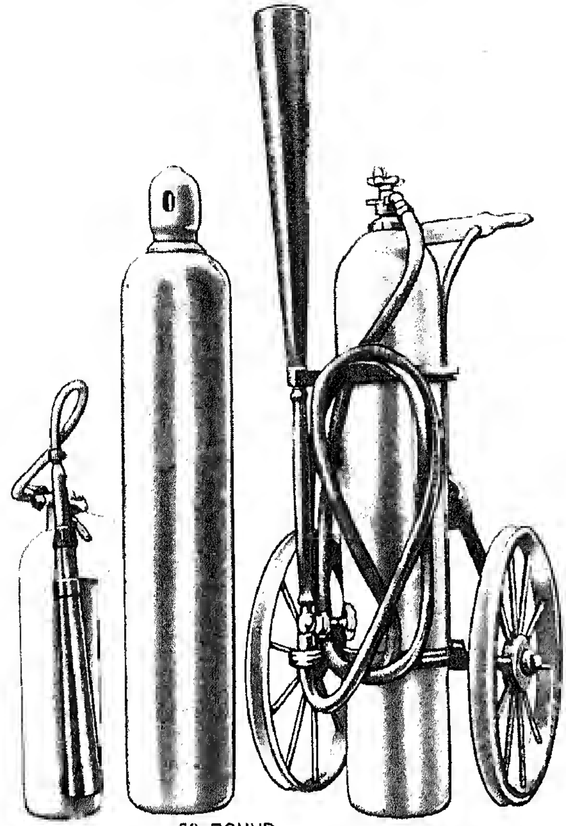


Figure 59. Carbon dioxide extinguisher and supply cylinder.

for electrical fires. Carbon tetrachloride absorbs water vapor, creating a corrosive mixture that attacks the extinguisher. The fluid must be kept in sealed containers as a protection against atmospheric moisture. Commercial carbon tetrachloride for cleaning or solvents should not be used in extinguishers. Whenever using a carbon tetrachloride extinguisher, particularly when hot metal may be present in a confined space, ventilate the area as much as possible and leave the area immediately when the fire is extinguished. The importance of getting out of the fumes produced cannot be overemphasized, since carbon tetrachloride and oxygen or water in contact with hot metal produce phosgene, a poisonous gas, in large quantities. Direct the stream of liquid toward the seat of the fire; if practical, walk around the fire to provide greater coverage. When used on tanks or vats, direct the extinguishing fluid against the container wall or other freeboard. Do not direct the stream into the burning liquid.

53. Handling Liquid Oxygen

The handling of liquid oxygen presents certain problems and hazards, which stem from two general sources: the chemical activity of oxygen and the extremely low temperatures involved.

a. Chemical Activity. One of the hazards results from the chemical affinity of oxygen for certain materials. Because liquid oxygen is chemically stable only as long as there is a complete absence of oxidizable material, equipment must be clean. All vessels or piping that

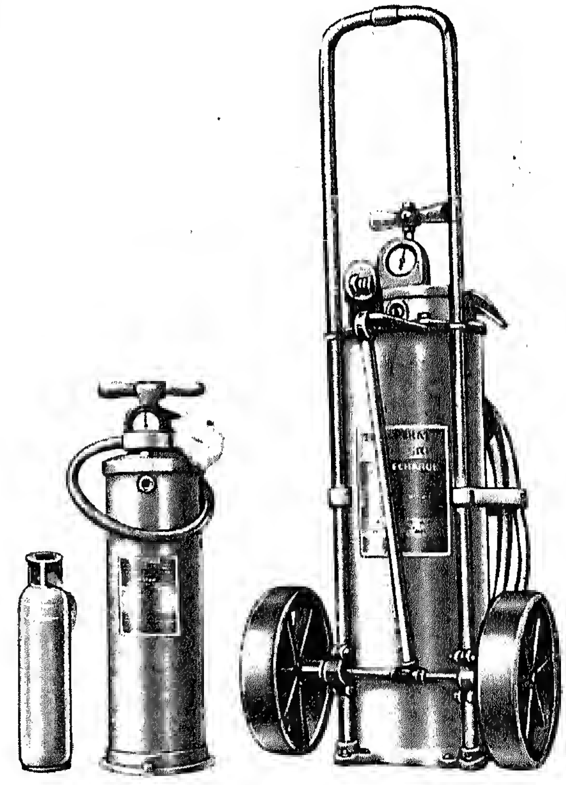


Figure 60. Carbon tetrachloride extinguisher.

will conduct liquid oxygen must be carefully cleaned before use. Complete provision must be made to prevent organic material from coming into contact with the product. The gas resulting from the vaporization of liquid oxygen will support rapid combustion, so liquid oxygen must be kept away from flames or flammable materials. Make sure there is adequate ventilation, thus avoiding oxygen concentration. Concentrations of gaseous oxygen are likely to cause rapid oxidization of numerous porous or finely divided organic materials, which would cause spontaneous combustion after only a few minutes of exposure. Pure oxygen mixed with flammable gas would result in a violent explosion.

b. Low Temperature. The very low temperature of liquid oxygen presents a hazard to persons working with it unless proper safeguards are taken. Careful training of personnel is essential to minimize accidental spilling, to avoid damage because of the coldness of the liquid. The liquid oxygen when spilled on flesh produces an effect similar to a scald or burn, and is treated the same. Unprotected surfaces of metal carrying the liquid are hazards.

c. Handling Precautions.

(1) Wear prescribed protective clothing and use prescribed equipment when handling liquid oxygen (fig. 61). These will include fireproof coveralls, plastic face shield, asbestos gloves, and sparkless tools.

(2) If exposed to dense oxygen vapors, do not smoke, work with open flames, or go near mechanical equipment until clothing has been changed or completely aerated.

(3) Keep adequate water supply, preferably safety showers, available in transfer and storage areas.

(4) Use only personnel who are familiar with the properties of liquid oxygen and with storage and transfer equipment in transfer operations.

(5) For transfer of liquid oxygen, use only containers and transfer lines designed for that particular purpose.

(6) For handling, storage, or transfer of liquid oxygen, use equipment designated for that particular purpose, and keep it clean and protected from dirt or oils when not in use.

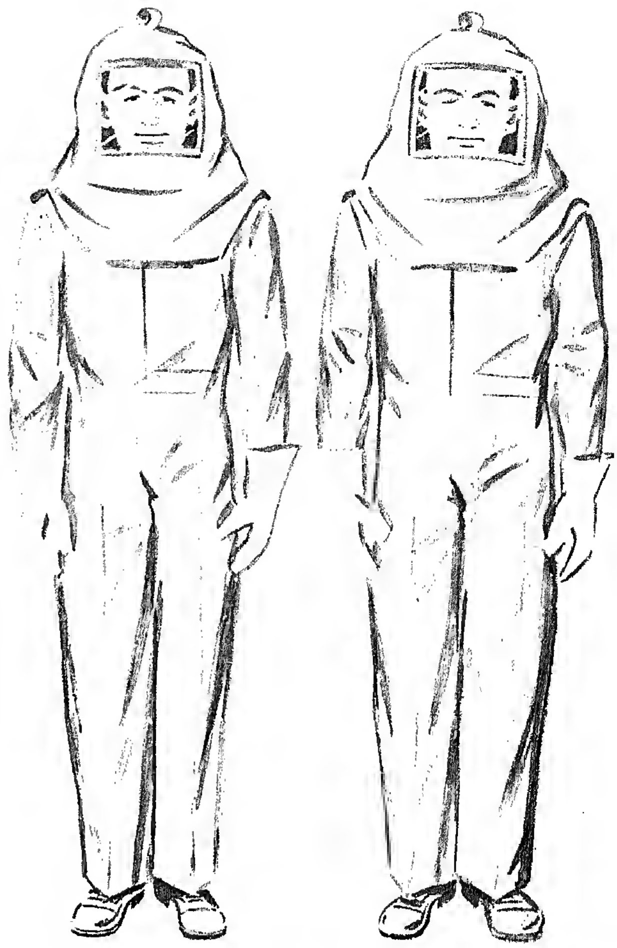


Figure 61. Protective clothing.

d. Toxicity. Although liquid oxygen is considered nontoxic, continued breathing of oxygen gas produces a narcotic, light-headed effect. However, prolonged breathing can cause death by over-oxygenating the blood. Breathing of cold oxygen vapor can damage the lungs.

e. Fire Hazards. See paragraph 52.

f. Permitted Equipment and Materials.

(1) Use only hose, piping, pumps, valves, gages, connections, evacuation equipment, and other equipment designed for liquid oxygen. Do not use this equipment for other than liquid oxygen service.

(2) Use only metals specified for use with liquid oxygen. Some of the suitable metals are:

(*a*) Pure nickel.

(*b*) Nickel-copper alloy.

(*c*) Inconel.

(*d*) Copper.

(*e*) Aluminum, or aluminum alloys.

(*f*) Annealed brass.

(*g*) 18–8 stainless steel.

(*h*) Silicon bronze.

(3) Because of the large temperature changes associated with oxygen service, make adequate provision for axial expansion and contraction of all systems carrying liquid oxygen. Avoid large tensile stresses because all metals lose ductility at low temperatures.

g. Prohibited Equipment and Materials.

(1) Do not use equipment not made or treated specifically for oxygen service. This applies particularly to pressure gages that may have been tested with oil or other objectionable material.

(2) Consider all materials unsuitable unless specifically approved. The following are known to be definitely unsuitable:

(*a*) Carbon steel.

(*b*) Cast iron.

(*c*) Plastics, unless specifically authorized.

(*d*) Rubber and related materials.

(3) Installed wiring that may be subjected to abrasion or other wear must be reduced to a minimum. Where required, it must be of an approved design or protected adequately by being placed in a metal casing or conduit. Install only specifically approved electrical equipment in oxygen handling or storage compartments. Be particularly careful to insure that proper electrical connections are made and that no overheating, shorting, or sparking will occur.

Section VI. FILLING CYLINDERS

54. Oxygen

Cylinders properly serviced and ready for filling with oxygen or nitrogen should have their valves closed to keep the cylinders dry and readily available for the charging rack. The following procedures should be used in charging cylinders with oxygen:

a. Fasten cylinder securely to the charging rack and attach the valve to the pigtail on the charging manifold. See figure 62 for a typical charging manifold. Do not fill less than four cylinders at a time, otherwise cylinders will be filled too rapidly and become overheated.

b. Tighten filling leads from charging rack to cylinders.

c. Open valves all the way and start oxygen compressor. Apply soapy water (using 100-percent pure olive-oil-base soap) to the valve connection to check for oxygen leaks, repeating at increasing pressures.

d. If cylinders become excessively warm to the touch, stop oxygen compressor and allow cylinders to cool to room temperature. Then start compressor again.

e. After cylinders are filled to operating pressure, close cylinder valves and apply soapy water (again using 100-percent pure olive-oil-base soap) over valve outlets to check for leaks. Pressure is checked by the gage on the cylinder rack.

f. Screw valve outlet cap tightly on valve outlet.

g. Screw valve protection cap on cylinder neck ring.

h. Remove cylinders to storage.

i. Plain and permanent markings are stamped into the metal of the cylinder shoulder, top, or neck. Markings must be in accordance with pertinent manuals and TB ENG 39.

j. The paint color, label tags, size, and other requirements are described in pertinent manuals and TB ENG 39.

k. Information on inspection procedures and servicing and maintenance will be found in TB ENG 39.

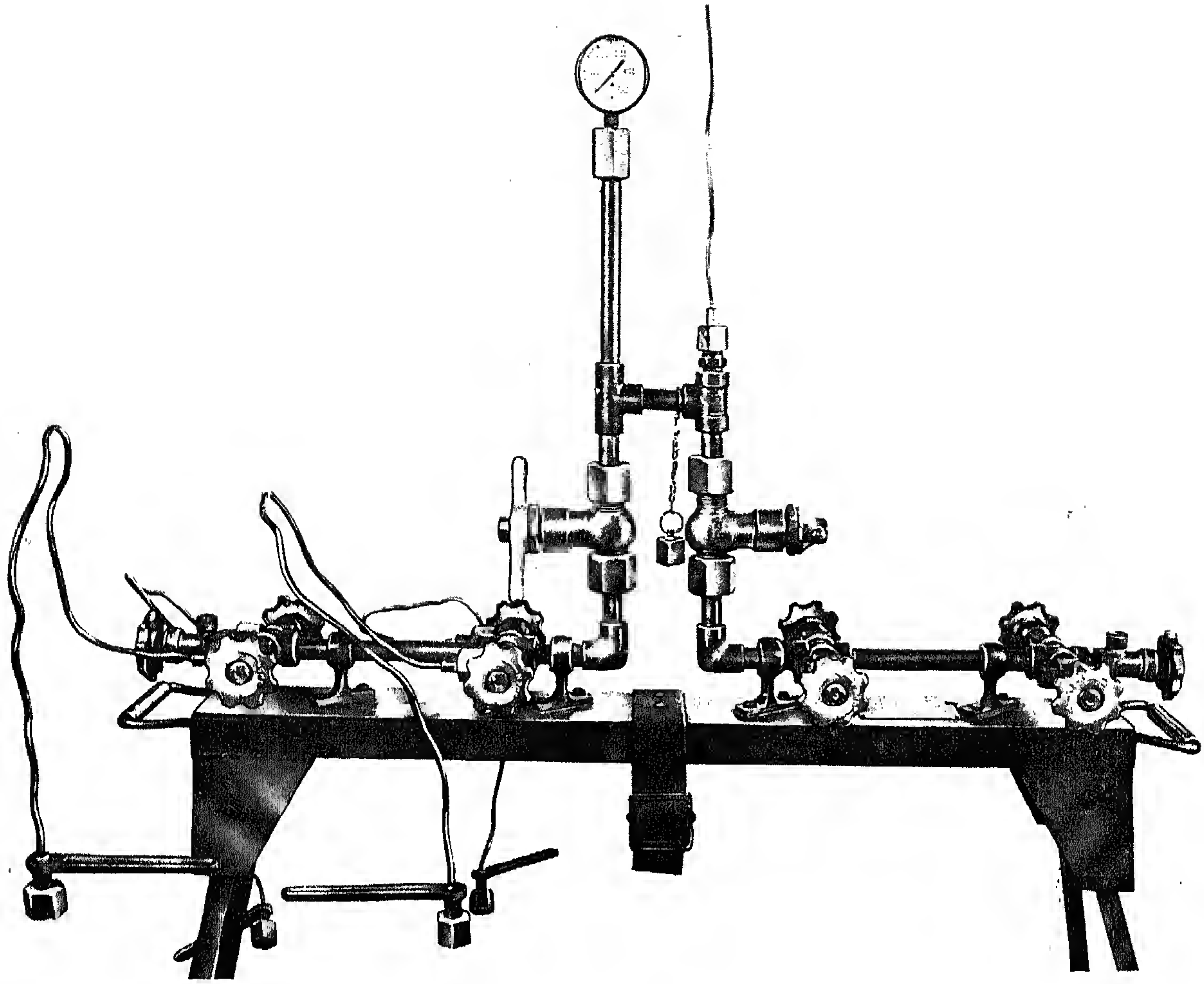


Figure 62. Cylinder charging manifold.

55. Nitrogen

If the plant is generating nitrogen and venting the oxygen to the atmosphere, the nitrogen cylinders are charged the same way as oxygen cylinders.

56. Refrigerants

The transfer of liquefied refrigerant gases from one cylinder to another is beyond the scope of this manual. It is covered in detail in AR 700–8120–1.

Section VII. STORAGE AND TRANSPORTATION OF LIQUID OXYGEN

57. Storage of Liquid Oxygen

Liquid oxygen in storage is susceptible to evaporation. This evaporation is accompanied by a buildup in pressure within the storage vessel because of the gaseous oxygen produced. For these reasons, storage vessels are specially designed and require special handling and operation. Liquid oxygen should be stored only in containers designed for use with oxygen. Filled liquid oxygen trailers or storage containers should be parked out of the direct rays of the sun to reduce boiloff loss.

58. Description of Liquid Oxygen Containers

Liquid oxygen storage containers are designed to insulate their contents and to keep the rate of evaporation, caused by heat leaking in

from surroundings, to a minimum. Basically the design of all liquid oxygen containers is the same—they are seamless, and normally cylindrical or spherical. Usually the cylindrical design is used so that the container may be more easily adapted for rail or truck transport. The containers are manufactured in various sizes.

a. Container. The principal design feature of the liquid oxygen container is its double wall of rolled steel construction. The area between the outer and inner shell is filled with insulating material and is maintained at a high degree of vacuum. The vacuum space decreases convection and conduction and the insulation blocks radiation. The liquid oxygen container can be compared functionally with the ordinary vacuum bottle. The inner tank is constructed of a steel that is highly resistant to corrosion by oxidation. Figure 63 illustrates a 9-ton liquid oxygen tank, trailer mounted. The flow chart is given in figure 64. Figure 65 illustrates a 35-ton liquid oxygen tank, skid mounted.

b. Vacuum Pump. A vacuum pump is installed on most large oxygen containers to maintain a high degree of vacuum between the inner and outer shells. The pump is usually of the rotary piston and cam type driven by an electric motor. A vacuum safety head is installed on the outer shell to prevent excessive pressures on the vacuum chamber if a leak occurs in the inner shell or in the piping between the shells. The safety head is set to relieve at a low pressure; usually this pressure setting is not in excess of 7 psig. An external vacuum pump connection is provided on each container so the insulation vacuum can be maintained if the installed pump fails to work, or if an external vacuum source is needed to assist in obtaining the required vacuum.

c. Vacuum Gage. A vacuum gage (fig. 66) is normally located near the vacuum pump. The gage may be a mercury, electronic, or thermocouple type. It shows the degree of vacuum either in the vacuum pump line or in the area between the inner and outer tanks. Its normal reading when the tank is filled with liquid oxygen should be less than 150 microns. Vacuum gages of the electrical type must be periodically

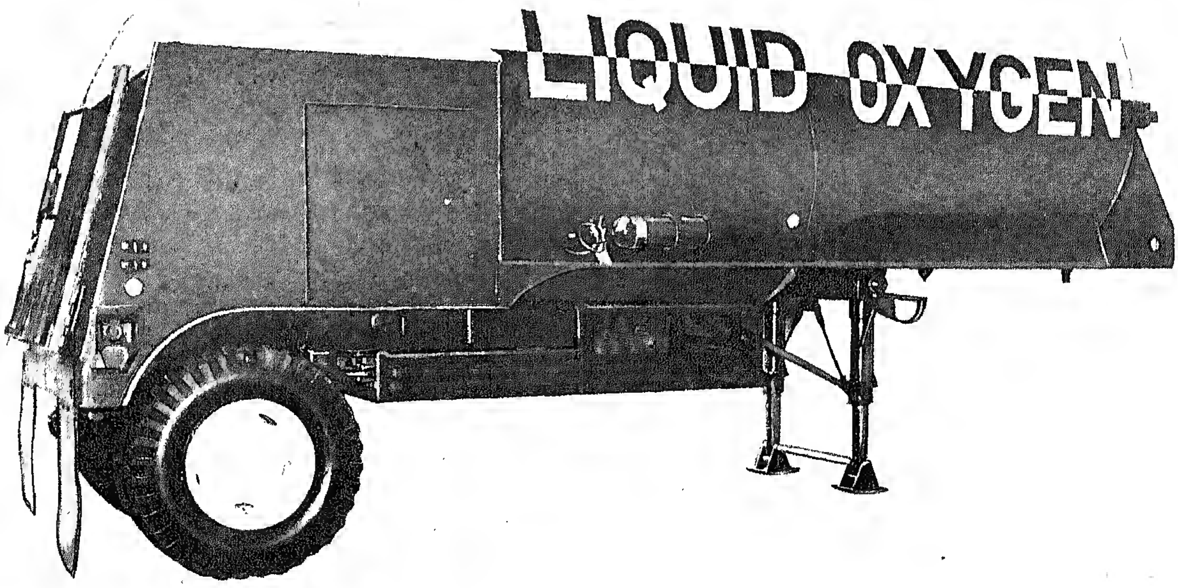
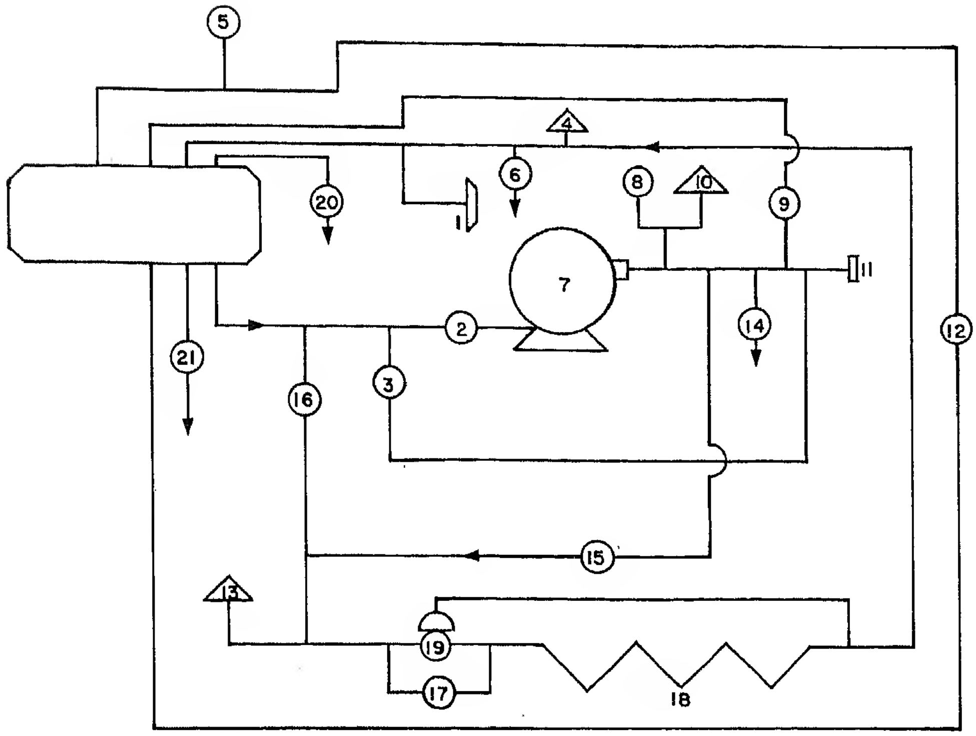


Figure 63. 9-ton liquid oxygen tank, trailer mounted.



1	Rupture disk	12	Liquid level gage
2	Suction valve	13	Safety valve
3	Filling valve	14	Discharge drain valve
4	Safety valve	15	Pump discharge valve to coil
5	Container pressure gage	16	Pump suction valve to coil
6	Gas phase blow down valve	17	Pressure regulator bypass
7	LOX transfer pump	18	Pressure building coil
8	Pump discharge pressure gage	19	Auto. press. bldg. regulator
9	Priming line valve	20	Full tricock
10	Safety valve	21	Empty tricock
11	Hose connection		

Figure 64. 9-ton trailer, schematic flow diagram.

checked by comparison with a mercury type gage, which may be connected to a special fitting on the 9-ton liquid oxygen tank or to the external vacuum pump flange on the 35-ton liquid oxygen tank.

d. Liquid Level Gage. A pressure differential gage is used to indicate the amount of liquid oxygen in the tank. The gage may be calibrated to read in pounds, gallons, or any other suitable unit of measure.

e. LOX Transfer Pump. The liquid oxygen transfer pump is mounted between the pump inlet line and the discharge line in the rear compartment of the oxygen container. It is a centrifugal type unit especially designed for the low temperatures encountered in liquid oxygen service.

f. Pressure Buildup Coil. The pressure buildup coil provides a method of increasing the vapor pressure inside the storage tank as a means of forcing the liquid oxygen out the discharge line in the event the container cannot be unloaded by gravity or with the aid of the liquid oxygen transfer pump. The coil consists of a series of parallel pipes, the ends of which are welded into cross pipes. Each of the pipes (except the cross pipes) is fitted with fins which aid in gathering heat from the air to evaporate the liquid oxygen in the coil. The evaporation of liquid oxygen results in gaseous oxygen. The resultant increase in volume increases the pressure in the inner tank. The increase in pressure resulting from the use of the pressure buildup coil depends upon the amount of liquid oxygen released into the coil.

g. Cleaning. Oxygen storage and handling equipment must be kept clean. Particular emphasis must be placed on the use of only those

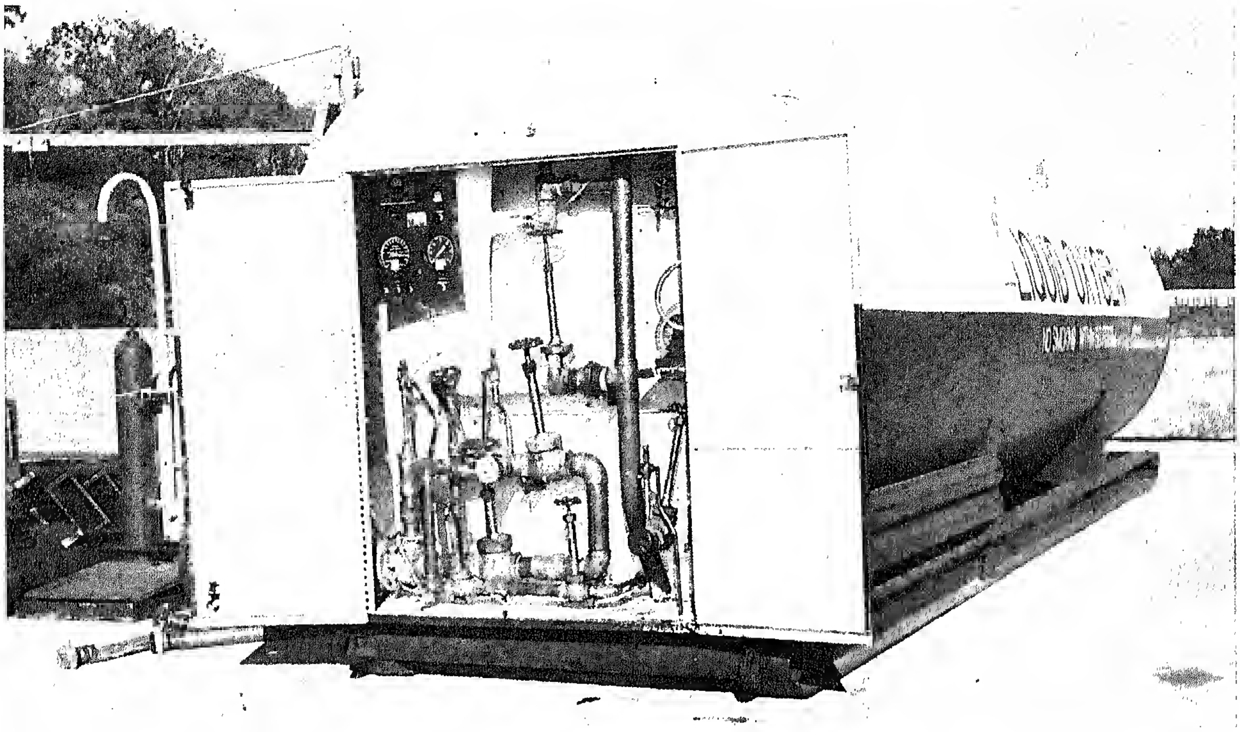


Figure 65. 35-ton liquid oxygen tank, skid mounted.

lubricants and cleaning and preserving materials and compounds prescribed in DA lubrication orders. Foreign material in oxygen lines and flexible hoses should be removed by a vacuum cleaner or by purging with clean, dry, oil-free, compressed air or nitrogen. Cleaning or repairs to the inner vessel of the container are subject to the following precautions:

(1) Purge with clean, dry, oil-free air or nitrogen to remove oxygen-rich atmosphere before work starts.

(2) If the interior surface is to be cleaned, use only the approved solvents. Clean, dry, oil-free air must be supplied to provide adequate ventilation for personnel working inside the container. A lifeline and an attendant must be present at all times when workmen are inside the container.

(3) After cleaning its interior, purge the container with warm, dry nitrogen gas heated to 30° above the boiling point of the cleaning agent. Continue purging until the temperature of nitrogen at the tank outlet rises to within 10° of input temperature.

59. Transportation

a. Tank Cars. There is no known requirement for the transportation of liquid oxygen by rail for the Army at this time.

b. Aircraft. There is no performance data covering air transportation of liquid oxygen at this time.

c. Liquid Oxygen Trailers. Transportation of liquid oxygen requires the same precautions as the road transportation of any flammable liquefied or compressed gas. These include the marking of containers as dangerous, the prohibition of smoking with 50 feet, the assignment of expert drivers, and the practice of the most stringent safe-driving techniques. In addition, the following precautions must be taken:

(1) Ground the trailer to eliminate hazard from electrical equipment and static electricity while loading, unloading, or in storage. A grounding device for use during transport of liquid oxygen may be fixed to the trailer chassis.

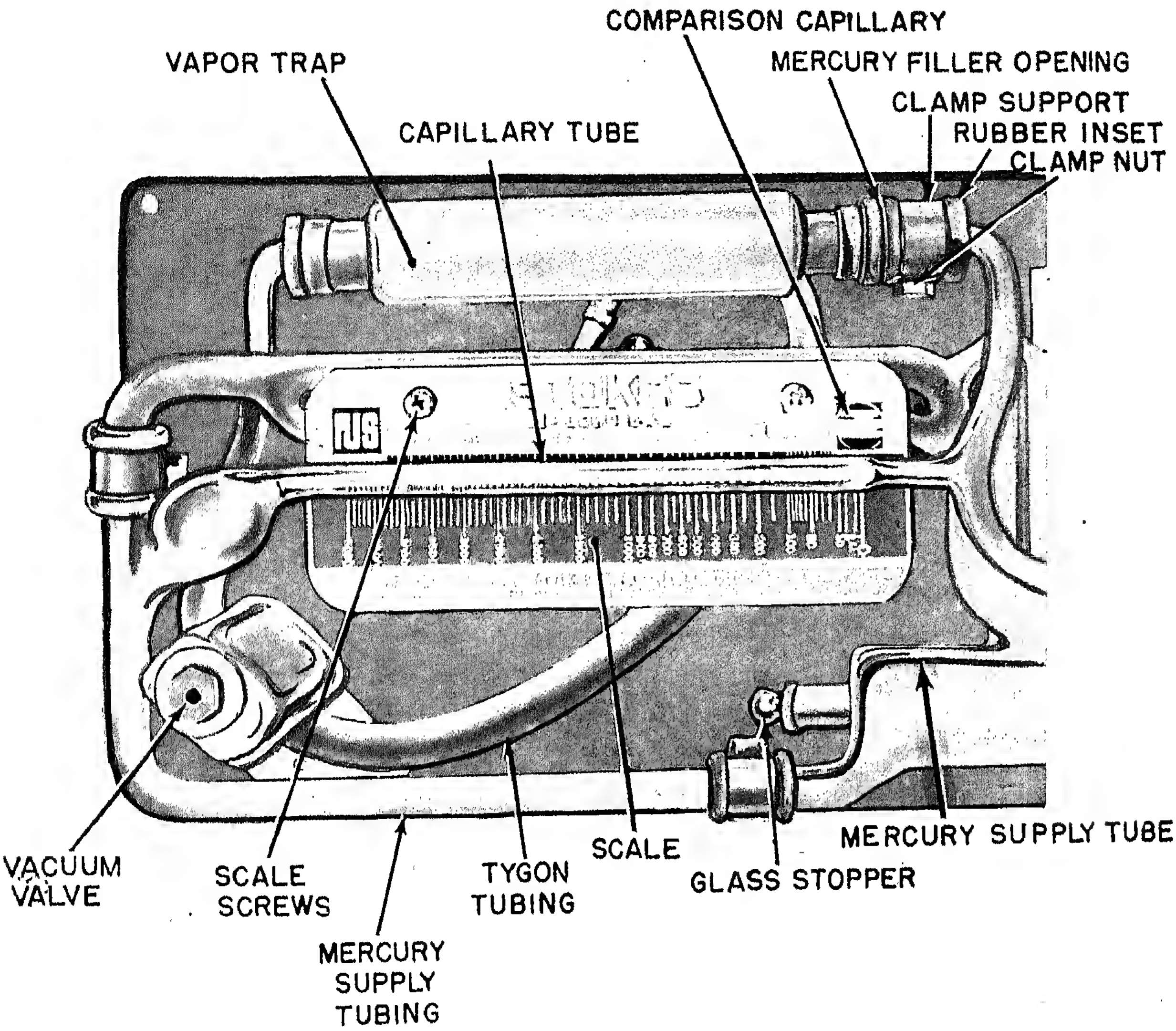


Figure 66. Typical vacuum gage.

(2) Inspect lines and hoses carefully to detect leakage. If leakage is minor and cannot be remedied during the transfer operation, make certain that it contacts no combustible materials. Use only approved oxygen-compatible thread sealer or Teflon tape and gaskets on liquid oxygen lines and hoses.

(3) Close completely all liquid container vent valves, before moving the trailer, to prevent the possibility of liquid spillage and to reduce boiloff loss during movement. Open the vent valves immediately after movement to release pressure buildup. If movement is for a considerable distance, relieve the pressure once an hour, or as dictated by experience based on ambient weather and temperature, road conditions, and container vacuum or mechanical condition. It is advisable to keep buildup pressure 5 psig below that recommended for pressure transfer.

CHAPTER 3

GENERATION OF CARBON DIOXIDE AND HYDROGEN

Section I. INTRODUCTION

60. Production Methods

a. Since pure carbon dioxide is found only in a few geographic areas, it is commonly produced for use by the following processes:

(1) By removing and purifying the carbon dioxide found in flue gas (called the flue gas or coke process).

(2) As a byproduct resulting from the production of alcohol.

(3) Through the catalytic conversion of a methanol-water mixture.

b. Hydrogen is produced by the following methods:

(1) Through the catalytic conversion of methanol vapor-steam mixture.

(2) By the electrolysis of water.

(3) By the dehydrogenation of certain petroleum products.

(4) By catalytic cracking of certain petroleum products.

(5) Through the reaction of sodium hydroxide, aluminum, and water.

(6) Through the reaction of calcium hydride and water.

61. Carbon Dioxide

a. Uses. Carbon dioxide as a solid (dry ice) was practically nonexistent until about 30 years ago. Now dry ice, for use by the soft drink and ice cream industry, makes up the bulk of the carbon dioxide generated. The ease with which carbon dioxide can change from a liquid to a gas also makes it an excellent refrigerant for many refrigerating systems. Moreover, because carbon dioxide is heavier than air and so has a blanketing effect on fires, it is widely used as the charge for fire extinguishers.

b. Physical Properties. The various physical properties of carbon dioxide were outlined in in paragraph 26*c*, where carbon dioxide was described as one of the components of air.

c. Chemical Properties. The chemical properties of carbon dioxide are also described in paragraph 26*c*.

62. Hydrogen

a. Uses. Hydrogen is widely used in burning, in underwater cutting, and in other applications where heat is a factor. Although it is flammable and explosive, it still is used in filling weather balloons, and occasionally dirigibles. However, as a filler for dirigibles it has been largely replaced by helium, which is nonexplosive.

b. Physical Properties. The outstanding physical property of hydrogen is its extreme lightness, for it weighs less than $\frac{1}{14}$ as much as air. Hydrogen gas is only slightly soluble in water and can be liquefied only at extremely low temperatures. When the pressure of liquid hydrogen is reduced, the liquid evaporates to form a transparent ice-appearing solid. Hydrogen is easily and rapidly absorbed by finely divided platinum. Additional physical properties, such as color, odor, and others, are given in table VIII.

c. Chemical Properties. Hydrogen is the first element in the periodic table and has at atomic weight of 1.008. It is designated by the chemical symbol H_2 indicating that the molecule of hydrogen has 2 atoms and thus has a molecular weight of 2.016. The gas is very active and forms many compounds with both metals and non-metals. This extreme activity is illustrated by its ability to combine with oxygen to form water. A high percentage of all chem-

.l reactions form water as a byproduct in this ınner. Moreover, a mixture of hydrogen and ' containing 4% to 75% by volume of hydrogen at atmospheric pressure may be ignited by just a spark, sometimes in a very violent fashion.

Section II. THEORY OF CARBON DIOXIDE AND HYDROGEN PRODUCTION

. Methanol-Water Process

Although several methods for producing carn dioxide and hydrogen were listed in paraaph 60, the methanol-water process, because is economical and suited for small-plant genation, is used in Army mobile gas-generating its. Basically all plants using the methanoliter reaction for the generation of carbon ɔxide and hydrogen will use similar methods r generation and purification to obtain end oducts, with the exception of the gas-absorbg agent in the system. Previously plants of is type used a sodium carbonate solution JA_2CO_3, for example) to absorb the carbon ɔxide from the hydrogen after generation. ɔwever, most units now use a solution of ɔnoethanolamine (MEA) rather than soda h for this purpose.

a. Raw Materials. The basic materials ›eded in the methanol-water process are methıol, monoethanolamine solution, and steam.

(1) *Methanol.* Methanol is the simplest of the organic alcohols and is represented by the formula CH_3OH. Methanol is a colorless liquid with an objectionable odor. It is poisonous and will cause blindness and death when taken internally or applied externally. It burns with a bluish flame to form carbon dioxide and water. Before the development of its synthesis, methanol was obtained commercially by the destructive distillation of wood (oak, maple, birch, and others) and appropriately received the name "wood alcohol." It is now manufactured by combining cabron monoxide and hydrogen under high pressure and in the presence of a copper oxide catalyst. In the methanol-water process a special grade of synthetic methanol is used which has less than0.02-percent ethanol (C_2H_5OH) by weight.

(2) *Monoethanolamine.* Monoethanolamine, or MEA as it is more commonly called, comes from a family of chemical compounds called amines which have a common NH_2 radical in their formula. It is manufactured commercially from ammonia and methanol, has a strong odor, and is flammable in the vapor state. Its most valuable property is its capability of absorbing carbon dioxide.

(3) *Steam.* Steam in this process is used both as one of the reactants and for heat applications.

b. Chemical Reactions. The total chemical reaction in the methanol-water process can be represented by the chemical equation:

$$CH_3OH + H_2O \xrightleftharpoons[302^\circ \text{ C. } (575^\circ \text{ F.})]{\text{Catalyst}} CO_2 + 3H_2$$

This equation states that 1 molecule of methanol plus 1 molecule of water react to form 3 molecules of hydrogen and 1 molecule of carbon dioxide. To insure that the reaction proceeds to the right, an amount of water in excess of the proportion shown in the formula, namely 37 percent by weight of methanol and 63 percent by weight of water, is used. The chemical reaction is carried out as shown in the formula in the presence of a catalyst and at a temperature of 302° C. (575° F.). Actually the reaction is completed by two nearly simultaneous primary and secondary reactions rather than the simple reaction shown above. These primary and secondary reactions are:

$$CH_3OH \rightleftharpoons CO + 2H_2 \text{ (Primary reaction)}$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \text{ (Secondary reaction)}$$

By adding the primary and secondary reactions, the total reaction of the process is obtained. An understanding of the intermediate reactions emphasizes the necessity for using excess water in the process.

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c. Basic Generation Procedure. The operations and principles covered in detail in chapter 2 are summarized below to enable a ready comparison with the procedures described in that chapter. The basic generating procedure for the production of carbon dioxide and hydrogen by the methanol-water process is as follows:

(1) Mixing and vaporizing of methanol in water (mixing and heat exchange).

(2) Conversion of the mixture to carbon dioxide and hydrogen (heat exchange, catalytic conversion).

(3) Separation of the carbon dioxide and hydrogen by the MEA solution (absorption).

(4) Separation of the carbon dioxide from the MEA (desorption).

(5) Purification of the carbon dioxide (scrubbing and adsorption).

64. Flue Gas Process

The flue gas process is also used to obtain carbon dioxide. Much of the unit used in this process is also used to obtain carbon dioxide. Much of the unit used in this process is similar in construction and operation to the methanol-water unit for it also employs the basic principle of using an amine for absorbing carbon dioxide.

a. Raw Materials. Materials needed for this process in addition to water are the MEA solution, potassium permanganate solution (KM^nO^4), and some type of fuel to obtain flue gas. Initially the fuel used in this process was coke, and so this method of obtaining carbon dioxide was known as the coke process. However, since coke was not always readily available at the sites where mobile units were in operation, a commercial grade fuel oil was substituted for coke because of the relative ease with which the oil could be transported. Consequently, though the method is the same, this procedure is often called the "fuel oil process."

b. Chemical Reaction. The primary chemical reaction in the fuel process is the combustion of oil which can be represented by the chemical equation.

$$C \text{ (oil)} + O_2 \text{ (air)} \rightarrow CO_2 \text{ (15\% by volume)} + \text{misc gases } (CO, N_2, \text{etc.})$$

The carbon dioxide forms a relatively weak gaseous mixture with the other flue gases obtained, and the rest of the process is concerned with removing carbon dioxide from the other gases of combustion.

c. Basic Generating Procedure. To manufacture carbon dioxide by this process, oil, coke, or natural gas is burned to produce carbon dioxide. A byproduct in burning the fuel is the resultant heat which is used in the production of steam for the rest of the process. The process, covered in detail in paragraphs 67 through 73, can be broken down as follows:

(1) Fuel burned (combustion).

(2) Gas cooled and washed (heat exchange and scrubbing).

(3) Gas routed countercurrently to MEA solution to absorb carbon dioxide (absorption).

(4) Carbon dioxide concentrated (99.9 percent) by boiling carbon dioxide out of the MEA solution (stripping).

(5) Carbon dioxide purified (scrubbing and adsorption).

65. Gas Absorbers

Absorption is used for purifying gas. In an absorption system the gaseous mixture (made up of the desired and undesired gas) is purified by exposing it to a liquid which has the capacity of dissolving the desired gas. The gas absorbed in this liquid thus is separated from the undesired gases and can be purified. The success of this method is based upon the amount of desired gas the liquid can absorb. The units designed for the manufacture of carbon dioxide use this principle.

a. Equipment. For efficient absorption, the liquid and gas must be in intimate contact for the maximum amount of time allowable relative to gas output. Consequently, this process is carried out in what is known as an absorption column (fig. 67) which is filled with a packing material that increases the surface contact between the gas and the liquid. The packing may be either a ceramic or a metallic material. It may be either in the form of hollow cylinders with height equal to diameter, commonly called Raschig rings (fig. 68), or shaped to resemble a saddle (appropriately termed berl saddles).

b. Process. In operation the gas mixture is introduced into the bottom of the absorption column and the absorbing liquid flows in at the top. The low-velocity liquid trickles down through the column over the rings or saddle packing which uniformly distributes the gas over the column's cross sectional area as it bubbles upward. The stack gas is vented to the atmosphere. This process of treating a gas by a liquid is termed scrubbing; the reverse process (treatment of a liquid by a gas) is termed stripping. Upon completion of the absorption operation, the absorbing agent is separated from the gas by elevating the temperature of the liquid or lowering its pressure, or both. This releases the gas from the absorbing agent.

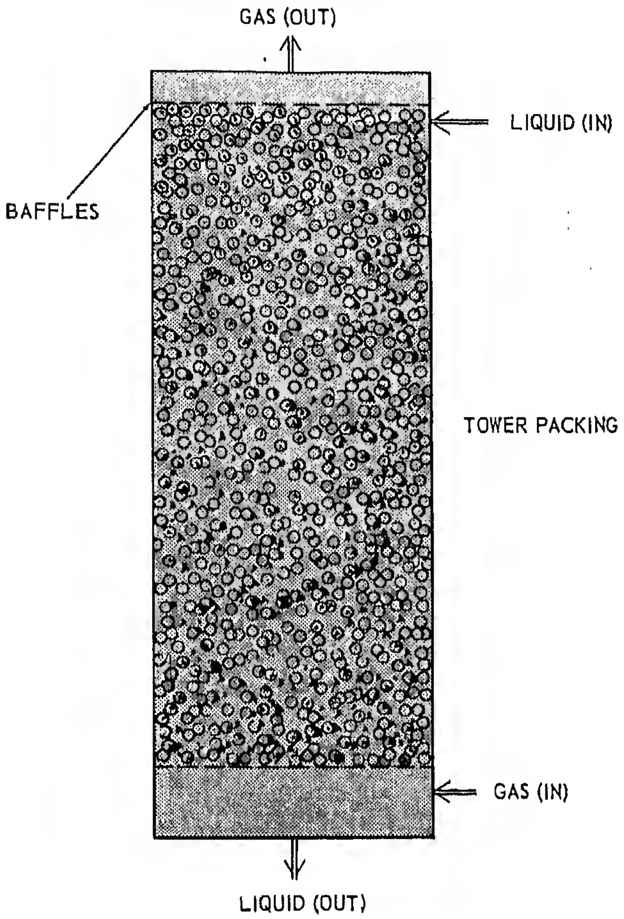


Figure 67. Cross sectional view of a typical packed absorption tower.

66. Adsorption

See paragraph 40*b*.

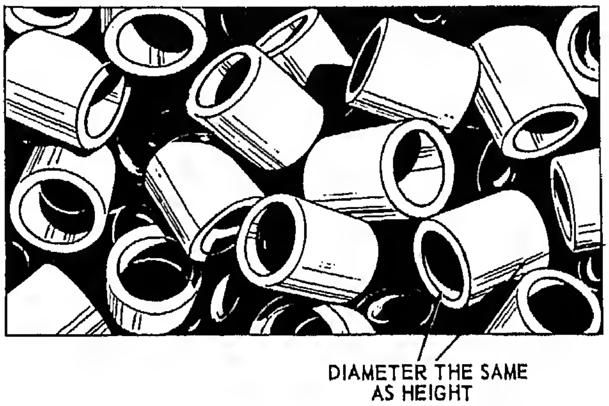


Figure 68. Typical tower packing of Raschig rings.

Section III. PRODUCTION OF CARBON DIOXIDE BY THE FLUE GAS PROCESS

67. Introduction

The flue gas process uses fuel to obtain the raw carbon dioxide gas. Raw gas is a term used to describe a gas which has not been purified. Units using this process are generally very economical to run because the burning of the fuel not only produces the desired carbon dioxide, but also produces process steam. The flow sheet for this process is shown in figure 69.

68. Gas-Generation System

a. Equipment. The gas-generation system consists of a boiler and its accessory equipment for producing raw carbon dioxide gas. Raw

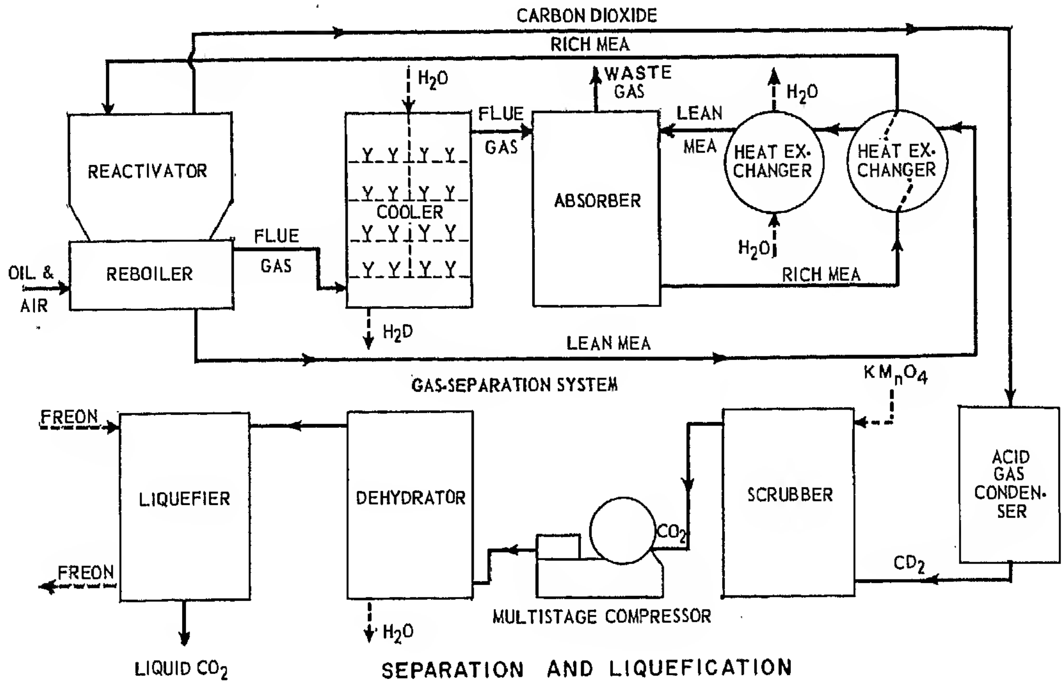


Figure 69. Simplified flow sheet of generation of carbon dioxide by the flue gas process.

carbon dioxide gas is produced by the combustion of an oil-air mixture under optimum conditions to produce a flue gas that contains the maximum amount of carbon dioxide. Under normal operating conditions, the amount will run between 14 percent and 15 percent.

b. Operation. Oil from an oil tank is pumped through a filter and strainer to the burner where it is mixed with an excess of air. At the burner, the fuel-air mixture is ignited and burned. The gaseous products from this combustion are oxygen, carbon monoxide, nitrogen, inert dust, and some miscellaneous gases, in addition to the 15 percent carbon dioxide.

c. Plant. The Army's carbon dioxide generating plant is a mobile, semitrailer-mounted plant capable of producing 300 pounds of liquid per hour. The plant, using the flue gas method, takes diesel oil as its source of carbon and atmospheric air as its source of oxygen (fig. 70 and 71). The basic trailer (fig. 70) is an enclosed van and drop-frame semitrailer designed specifically to house the production equipment. Hinged access doors on the roof, rear, front, and sides provide adequate clearance for the removal of larger component parts. The trailer is 35 feet long, 9 feet wide, and 11½ feet high, weighs approximately 23 tons, and can be towed with an M52 tractor or equivalent vehicle.

69. Gas-Separation System

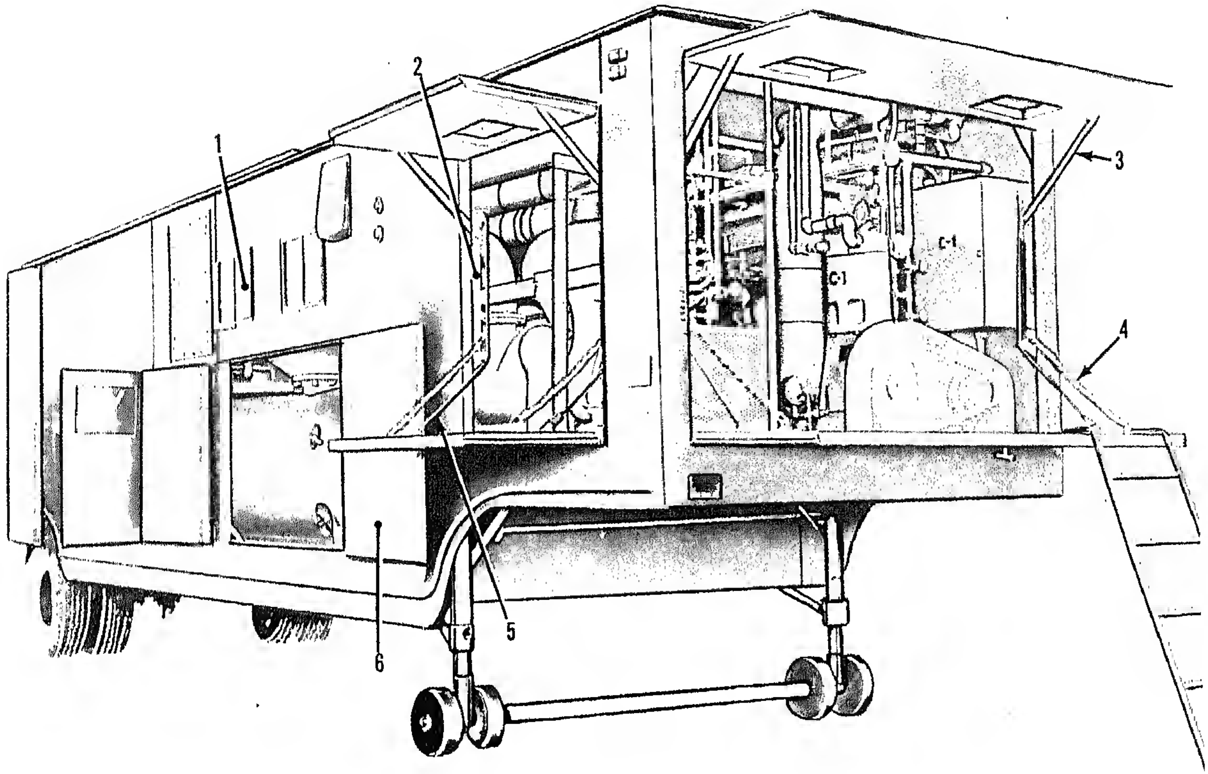
a. Equipment. The basic principle in the separation of the carbon dioxide from foreign gases in this process is identical to the methanol-water process which used monoethanolamine (MEA) as the absorbing agent in removing pure carbon dioxide from the other materials in the flue gas. Essentially the gas-separation system consists of four parts:

(1) A burner in which the fuel is mixed with air and ignited.

(2) A boiler (reactivation unit) where a good deal of the heat is removed from the flue gas and used in the separation of carbon dioxide from the MEA solution after absorption.

(3) A flue gas cooler which further cools the flue gas and also serves to remove some of the impurities.

(4) An absorber in which the carbon dioxide is extracted from the flue gas by the MEA solution. The flue gas containing carbon dioxide enters the absorber, and waste gas free of carbon dioxide is vented from the absorber.



1 Window
2 Counter balance
3 Brace
4 Chain
5 Wire rope
6 Door

Figure 70. Carbon dioxide generator, road side.

b. Operation.

(1) *Boiler.* It can be seen from table VII that the amount of carbon dioxide absorbed by the MEA solution increases with a decrease in temperature. Therefore, before carbon dioxide can be removed effectively from the flue gases the gas must be cooled. Consequently the gas from the furnace passes directly into a two-pass boiler where the temperature is reduced to approximately 454°C. (850°F.) In the process shown, this exchanger actually forms one part of the reactivation unit.

Table VII. Effect of Temperature, Pressure, and Solution Concentration on Solubility of CO_2 in MEA

Temperature °C.	Molarity [1] of MEA	Partial Pressure of CO_2, mm. Hg.	Solubility Moles CO_2 Moles of MEA [2]
0______	0.5	745.8	1.110
0______	0.5	256.3	.990
0______	0.5	45.3	.817

Table VII. Effect of Temperature, Pressure, and Solution Concentration on Solubility of CO_2 in MEA—(Continued)

Temperature °C.	Molarity [1] of MEA	Partial Pressure of CO_2, mm. Hg.	Solubility Moles CO_2 Moles of MEA [2]
0______	0.5	10.6	.675
25______	0.5	735.7	1.004
25______	0.5	251.8	.886
25______	0.5	99.6	.795
25______	0.5	44.2	.720
50______	0.5	661.3	.880
50______	0.5	228.3	.757
50______	0.5	40.1	.596
75______	0.5	475.8	.685
75______	0.5	130.3	.584
75______	0.5	50.0	.476
0______	2.0	754.4	.900
0______	2.0	206.1	.776
0______	2.0	79.4	.718
0______	2.0	11.4	.601
25______	2.0	736.4	.795
25______	2.0	252.2	.697
25______	2.0	98.6	.623
25______	2.0	44.2	.589
50______	2.0	668.2	.689

Table VII. Effect of Temperature, Pressure, and Solution Concentration on Solubility of CO_2 in MEA—(Continued)

Temperature °C.	Molarity [1] of MEA	Partial Pressure of CO_2, mm. Hg.	Solubility Moles CO_2 Moles of MEA [2]
50	2.0	183.1	.607
25	2.0	44.2	.589
50	2.0	668.2	.698
50	2.0	183.1	.607
50	2.0	70.9	.556
50	2.0	10.1	.489
75	2.0	477.0	.560
75	2.0	130.6	.474
75	2.0	51.1	.430
0	5.0	751.5	.761
0	5.0	272.2	.679
0	5.0	206.2	.649
0	5.0	80.1	.600
25	5.0	742.9	.657
25	5.0	254.9	.601
25	5.0	98.7	.563
25	5.0	44.6	.539
50	5.0	677.0	.574
50	5.0	245.3	.527
50	5.0	71.5	.505
50	5.0	10.4	.453
75	5.0	518.1	.493
75	5.0	142.6	.460
75	5.0	54.8	.418
0	9.5	752.4	.622
0	9.5	272.2	.592
0	9.5	79.2	.568
0	9.5	11.4	.538
25	9.5	735.9	.588
25	9.5	252.2	.554
25	9.5	99.0	.532
25	9.5	44.8	.519
50	9.5	701.3	.538
50	9.5	255.3	.522
50	9.5	74.3	.492
50	9.5	10.8	.443
75	9.5	559.7	.468
75	9.5	153.1	.458
75	9.5	56.7	.424
25	12.5	749.1	.548
25	12.5	256.3	.518
25	12.5	45.4	.521
50	12.5	716.2	.525
50	12.5	259.5	.501
50	12.5	196.0	.495
50	12.5	75.6	.483
50	12.5	10.9	.467
75	12.5	629.9	.479
75	12.5	168.1	.453
75	12.5	64.2	.395

[1] The molarity of a compound (such as MEA) or element dissolved in water is the number of gram moles dissolved per liter of solution.

[2] Although the solubility of CO_2 per mole of MEA decreases as the concentration of MEA increases, the solubility of CO_2 *per volume of solution* increases.

(2) *Flue gas cooler.* From the boiler, or reboiler as it is called in the plant, the gas is fed into the bottom of a flue gas cooler. In the cooler, water is directed countercurrently to the gas flow, further reducing the gas temperature to approximately 39°C. (100°F.). The water also acts as a scrubbing agent for removing sulfur dioxide and dust from the gas.

(3) *Absorber.* The MEA solution is now fed from the rebuilder through the MEA cooler into the top of the absorption column. The solution flows downward over the packing and comes in contact with the upward-flowing flue gases. During this time the carbon dioxide is absorbed in the MEA, and the other flue gases which are not soluble in the solution rise to the top of the column. After the latter leave the column the small amount of MEA which is invariably entrained is removed by a separation device and fed back into the column. The flue gas is then vented to the atmosphere. Simultaneously the MEA and carbon dioxide mixture is pumped from the bottom of the column. In this process, the absorber provides the mixing chamber, the absorption area, and the distribution devices for the required substances. The operator must have the skill to produce the exact conditions which will induce the maximum transfer of carbon dioxide to MEA. The temperature and pressure must be carefully controlled.

(4) *Reactivation unit.* To complete the separation, the MEA solution and carbon dioxide are dissociated by heating the mixture. This is done by first passing the rich MEA solution through a heat exchanger which acts as a preheater in that it raises the temperature of the mixture to approximately 99°C. (210°F.), before the separation operation. From the preheater, the hot solution passes to the reactivation unit. Here the mixture is sprayed through a series of nozzles,

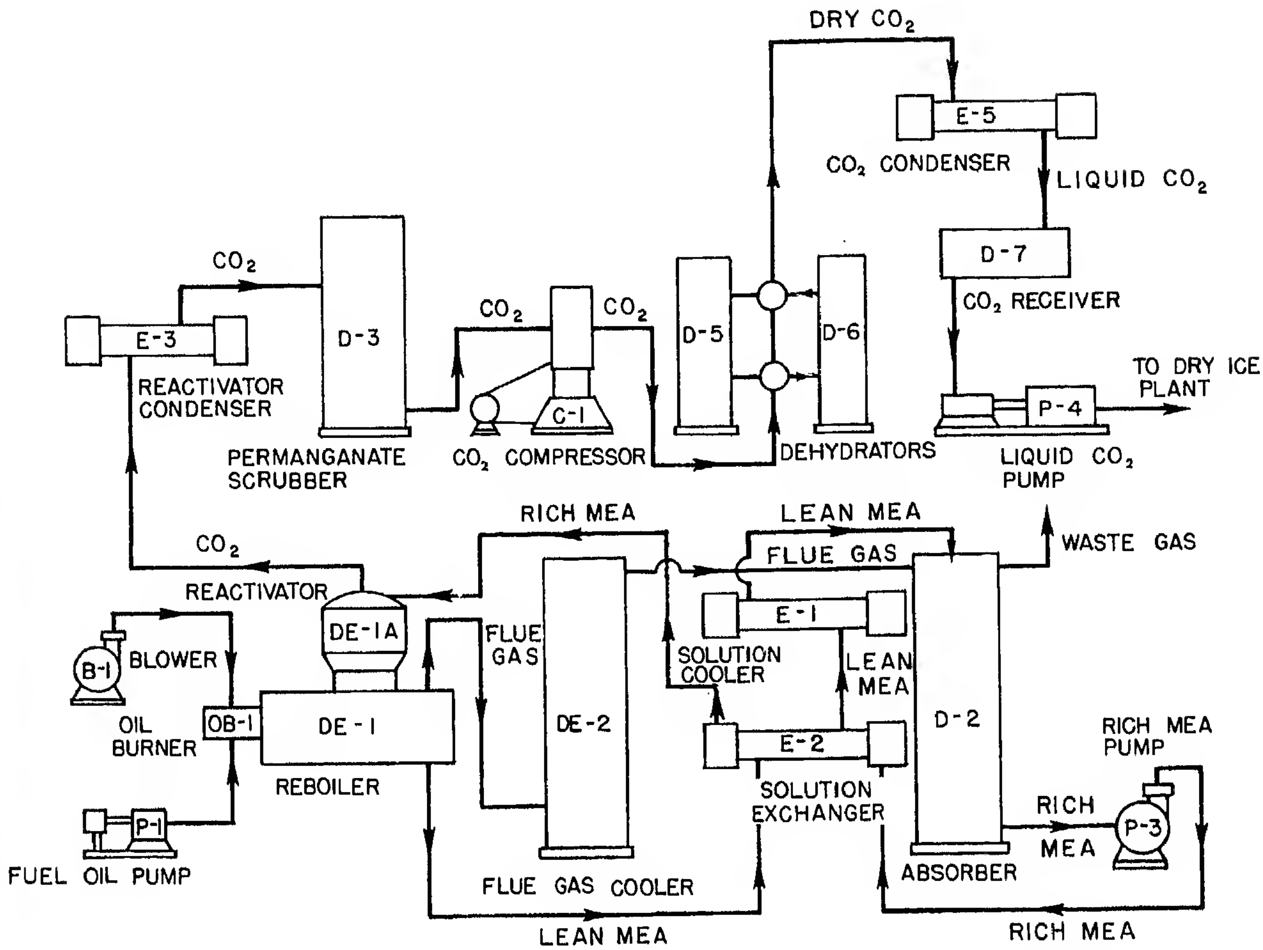


Figure 71. Flow system, carbon dioxide plant.

and passes countercurrent to the hot vapors rising from the boiler. The dual-purpose reboiler further raises the temperature of this rich MEA solution sufficiently high to dissociate the MEA from the carbon dioxide. The hot lean MEA solution (MEA without carbon dioxide) is then drained from the bottom of the reactivator unit and is used as the heating medium for the rich MEA solution, flowing through the aforementioned preheater. From the preheater, the lean MEA is reduced still further in temperature in a water-cooled heat exchanger, after which it is directed back to the absorber to complete the MEA cycle.

70. Gas Purification and Liquefaction

The remainder of the flue gas process, namely the purification of the gas and the final liquefaction, is very similar to that outlined in the discussion covering the methanol-water process (sec. VII). Briefly, gas purification and liquefaction involve the units discussed in the following paragraphs.

a. Heat Exchanger. The liberated carbon dioxide from the reactivator leaves the unit at a purity in excess of 99 percent. The gas temperature is lowered by passing it through a heat exchanger and into a gas holder. This operation condenses the moisture from the gas which contains entrained MEA and, consequently, the drained condensate is returned to the bottom of

the absorber where it is mixed with the rich MEA and recycled.

b. Scrubber. After passing through the heat exchanger the gas is bubbled up through the scrubber which is a hollow cylinder filled to a predetermined level with a potassium permanganate ($KMnO_4$) solution. This removes the impurities in the gas which affect its odor and taste, and is the final purification step before the gas is compressed.

c. Compressor. The gas is then compressed in a multistage (usually two stages) compressor to between 300 and 350 psi. As in the previous process, there is an intercooler between the stages of compression and an aftercooler after the last stage of compression. These usually can lower the temperature to within approximately —6.7°C. (20°F.) of the cooling water temperature.

d. Dehydrator: As a result of the gas travelling through the intercooler and aftercooler of the compressor, the gas is now saturated with water. Consequently, before cooling the gas below the freezing point of water the gas is passed through a dryer or dehydrator (containing alumina, for example) where the water is adsorbed by the adsorbent. This action prevents freezing and clogging of the valves, piping, and associated equipment of the system since the gas temperature drops below 0°C. (32°F.). These dryers are normally connected in parallel so that one may be reactivated (water removed from the adsorbent) while the other is in use.

e. Liquefier. The dehydrated gas now passes through a final heat exchanger or liquefier where it is cooled to approximately —18°C. (0°F.) by liquid freon which, at this pressure, is sufficiently cool to liquefy the carbon dioxide.

f. Receiver. The liquid carbon dioxide is then collected in a large tank called a receiver where it can be pumped either into carbon dioxide cylinders or into the solidifying plant where it is converted to dry ice.

71. Spray Ponds and Cooling Towers

Water is most commonly used as a cooling medium in gas generating plants, particularly in making carbon dioxide and acetylene gas. As a considerable amount of water is used in these processes, spray ponds or cooling towers are usually employed to cool the water. If a closed recirculating water system is used, the spray pond or water tower will lower the water temperature leaving the gas-generating plant about —3.8°C. to 10°C. (25° to 50°F.), depending upon the relative humidity of the outside air. In the water-tower method of cooling, which uses a vaporization principle, the heated water is ejected downward from a series of fine spray nozzles located at the top of a spray tower. (The nozzles spray water upward if a spray pond is used.) During this process part of the water tends to vaporize, and since vaporization requires heat, the rest of the water in the system must supply it. This effectively lowers the water temperature. To increase the tower's efficiency and facilitate additional cooling, moving air supplied by cooling fans flows countercurrent to the water in the tower as shown in figure 72. During this operation, some water is always entrained in the air, carried out the top, and lost. Consequently, a makeup water supply system must always be used with spray ponds or towers.

72. Spray Towers

A spray tower, similar in design to that illustrated in figure 72, but enclosed in a column, can also be used for cleaning as well as cooling. The impure gas enters the bottom of the column, passes through a spray, and is washed. Since the wash water is either dumped or recirculated after passing through a filter, the column proper has the advantage of low maintenance because there is no danger of its clogging.

73. Freon System

Freon is used in the final step in the liquefaction process to sufficiently lower the temperature of the carbon dioxide gas so it will liquefy. The mechanical refrigeration system involves a change in phase of freon from the liquid to the gaseous state. This requires the addition of heat from some outside source. In this case the heat remaining in the carbon dioxide gas provides the necessary heat of vaporization to the freon. Upon giving up this heat, however, the carbon dioxide drops below its critical temperature and changes from the gaseuos to the liquid state.

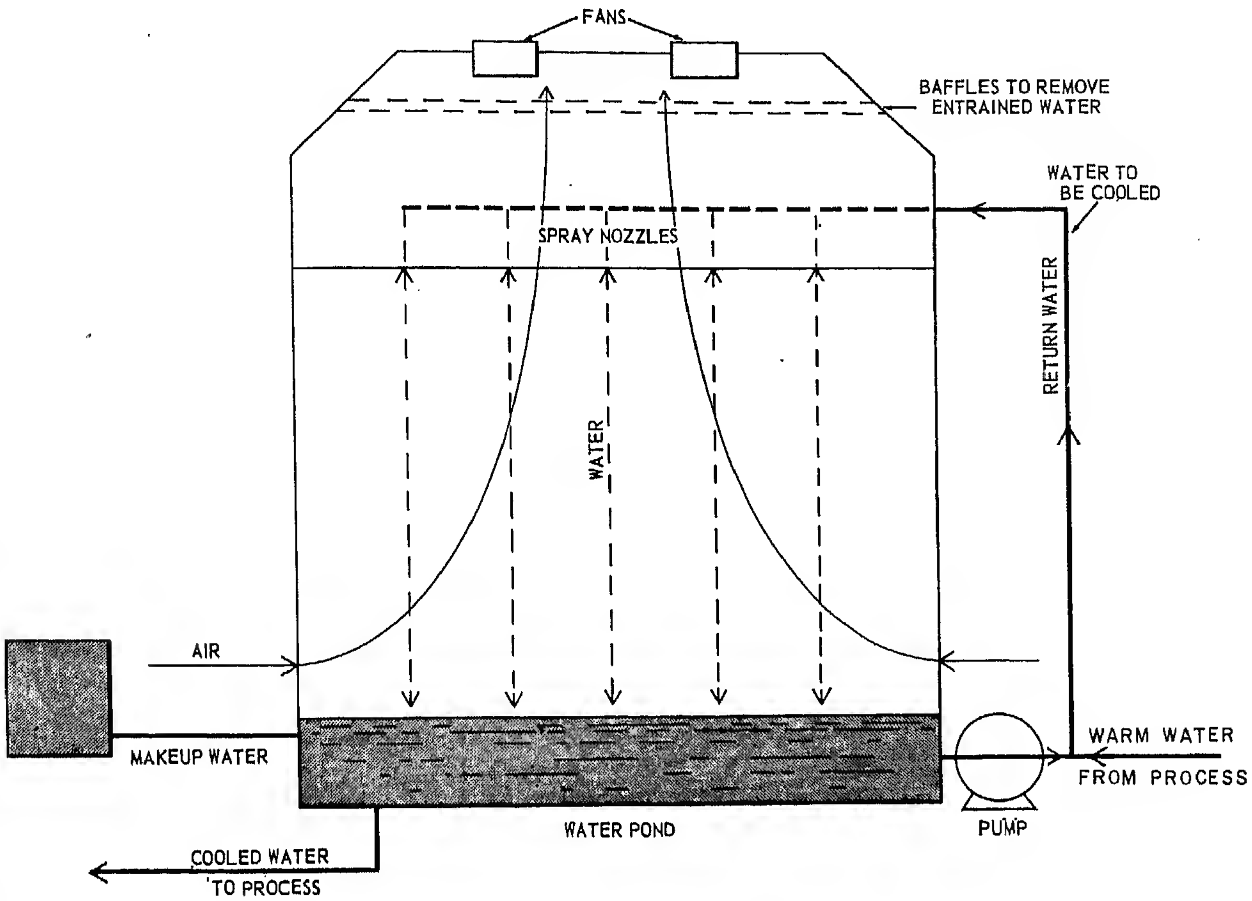


Figure 72. Cross sectional view of typical cooling tower.

Section IV. CARBON-DIOXIDE SOLIDIFYING PLANT

74. Introduction

In the preceding sections, two methods currently used for the generation of carbon dioxide by the Army in the mobile gas-generating units have been discussed. Each of these units obtained carbon dioxide in the liquid state. However, as was mentioned in paragraph 61, the demand for solid carbon dioxide is extremely high. It also is cheaper and more convenient to ship carbon dioxide in the solid rather than the liquid state. This is especially true when the gas is being generated in one area and transferred by air freight to another. Consequently, this section will cover a description of a typical plant for the solidifying of carbon dioxide. This plant is commonly called a dry ice plant.

75. Theory of Solid Carbon Dioxide Production

a. States of Carbon Dioxide. If liquid carbon dioxide is cooled to a temperature of —57°C. (—70°F.) at 60 psi, it will change into an ice-appearing substance which is solid carbon dioxide. This temperature of —57°C. (—70°F.) is known as the triple point of the substance because at this temperature it can exist as a gas, liquid, or solid. Below this temperature it can exist only as a gas or solid, depending on the pressure. In the plant under discussion, the transformation of liquid carbon dioxide to solid carbon dioxide is carried out at atmospheric pressure and at the temperature of —79°C. (—110°F.) at which dry ice is formed. When a block of the solid carbon dioxide is

subjected to heat, it changes directly into the gaseous state by a phenomenon known as sublimation and leaves no liquid residue as is the case when water ice melts; thus, the appropriate term "dry ice."

b. Methods of Producing Dry Ice. Liquid carbon dioxide is transformed into solid carbon dioxide by the cooling effect of its own vaporization. The process is summarized as follows:

(1) *Expansion.* The liquid is expanded through a nozzle to near atmospheric pressure to form snow (solid carbon dioxide) and gaseous carbon dioxide. The sudden pressure change causes part of the liquid to be flashed or vaporized. The heat is extracted from the unvaporized liquid which causes the liquid to be cooled and changed to snow. The amount vaporized compared to the amount solidified is dependent upon the balance of heat. The heat of vaporization will be equal to the heat extracted from the liquid as the liquid is cooled sufficiently to solidify it. Therefore, the cooler the liquid is before expansion, the smaller the amount of gas and the greater the amount of snow that is formed.

(2) *Recompression.* The gas is recompressed and recooled to complete the cycle. Several cycles have been devised to bring about recompression, and although the simpler ones require less capital investment, they do not produce as high a yield of solid to gas and are, therefore, less efficient. These cycles are listed as follows:

(*a*) The simple cycle in which the gas is expanded and recompressed.

(*b*) The precooled cycle in which the expanded gas is allowed to cool the unexpanded liquid.

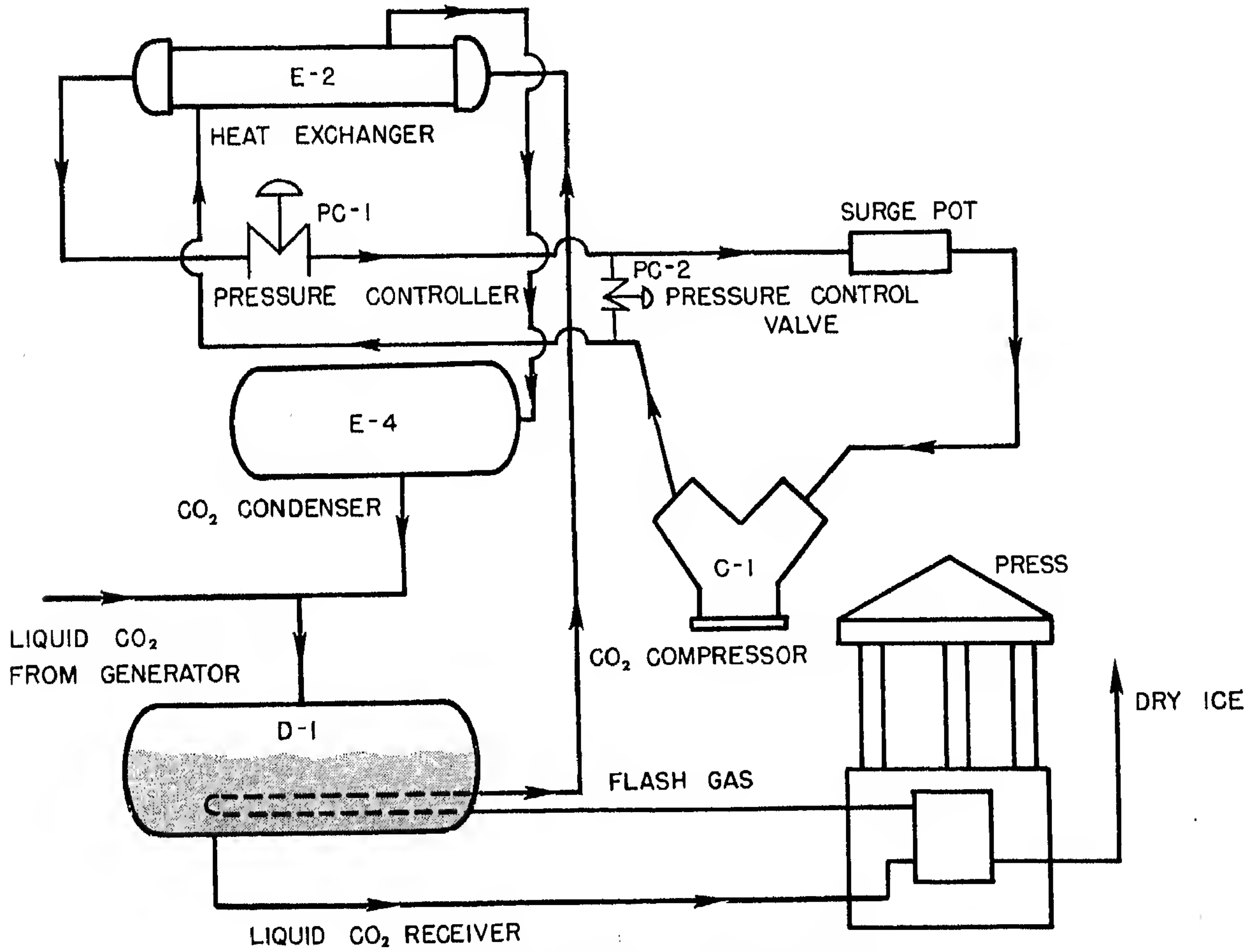


Figure 73. Flow system, CO_2 solidification plant.

(c) The mechanical refrigeration cycle in which some form of external refrigeration is used to cool the gas to a liquid.

(d) The pressure cycle in which the snow is formed at the triple point or under pressure rather than at atmospheric pressure.

(3) *Army type unit.* The unit currently in use by the Army combines cycles (b) and (c) by first precooling the liquid by a freon refrigeration system and then using the gas to further cool the liquid. The liquid is sufficiently precooled before expansion to produce a high yield of snow.

76. Manufacture of Dry Ice

a. Conversion to Dry Ice. The liquid carbon dioxide from either the methanol-water plant or flue gas plant is used as the feed material for the dry ice plant. As shown on the flow sheet (fig. 73), the liquid is pumped from either of the units mentioned above into a carbon dioxide receiver or temporary storage tank. The liquid is drawn from the receiver as needed and fed into the carbon dioxide press of the dry ice plant which converts the liquid into solid carbon dioxide. The press is operated at slightly above atmospheric pressure; thus, as the liquid is drawn into the press through a nozzle, it is flashed (pressure suddenly released, reducing the temperature) and 50 to 70 percent of the liquid forms snow. The rest of the liquid is vaporized and is removed from the press as pure carbon dioxide gas which must be reliquefied.

b. Reliquefaction. The equipment and method used for recompressing and recooling the gas in this section of the unit is similar to the liquefaction section of the carbon dioxide generating units. Before passing into the first stage of compression, the gas flows back through a coil in the carbon dioxide receiver and precools the liquid to increase the plant efficiency as explained in paragraphs 67 through 73 and 85 through 91. The gas is then split into two streams. One of these flows directly into the first stage of the compressor, and the other passes through a carbon dioxide heat exchanger and into the compressor. The compressor is a two stage unit with an intercooler and aftercooler and recompresses the gas to approximately 300 psi. The high-pressure gas leaves the aftercooler and is further cooled in the heat exchanger by the low-pressure gas. Next, it passes into a liquefier where the gas is cooled to approximately —18°C. (0°F.) by a conventional freon refrigeration system and is liquefied. The liquid then is transferred to the carbon dioxide receiver and after a period of time is drawn off to the press to complete the cycle.

c. Operation of the Press. A hydraulic press similar to that shown in figure 75 is used. The operation of the press, which consists of an upper and a lower ram, is simple. After snow has formed in the press, the liquid carbon dioxide feed is shut off, the upper ram is lowered under a pressure of 2,500 pounds, and the snow is compressed to near maximum density. The upper ram is then raised, leaving a block of ice on the lower ram with a density between 1.5 and 1.6. The lower ram is lowered and the block of ice is removed and cut into pieces of the desired size. If not used immediately the blocks are placed in storage units.

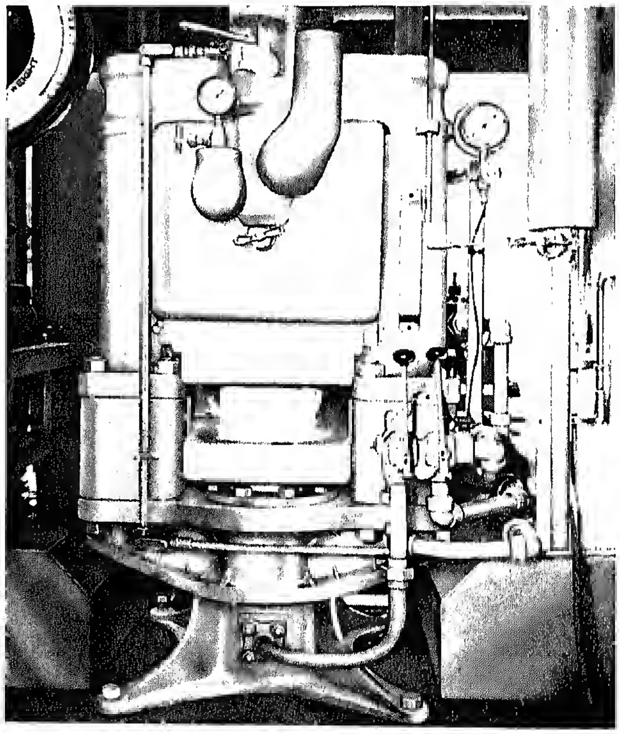


Figure 74. Typical mobile unit, dry ice press.

Section V. PLANT LAYOUT

77. Introduction

The purpose of this section is to acquaint operating personnel with the location or plan of the various components of the methanol-water and flue gas plants. Because of the simplicity of the units in the dry ice plant it will not be covered. Block flow diagrams shown in figures 75 and 76 identify and show location of the equipment and are self-explanatory.

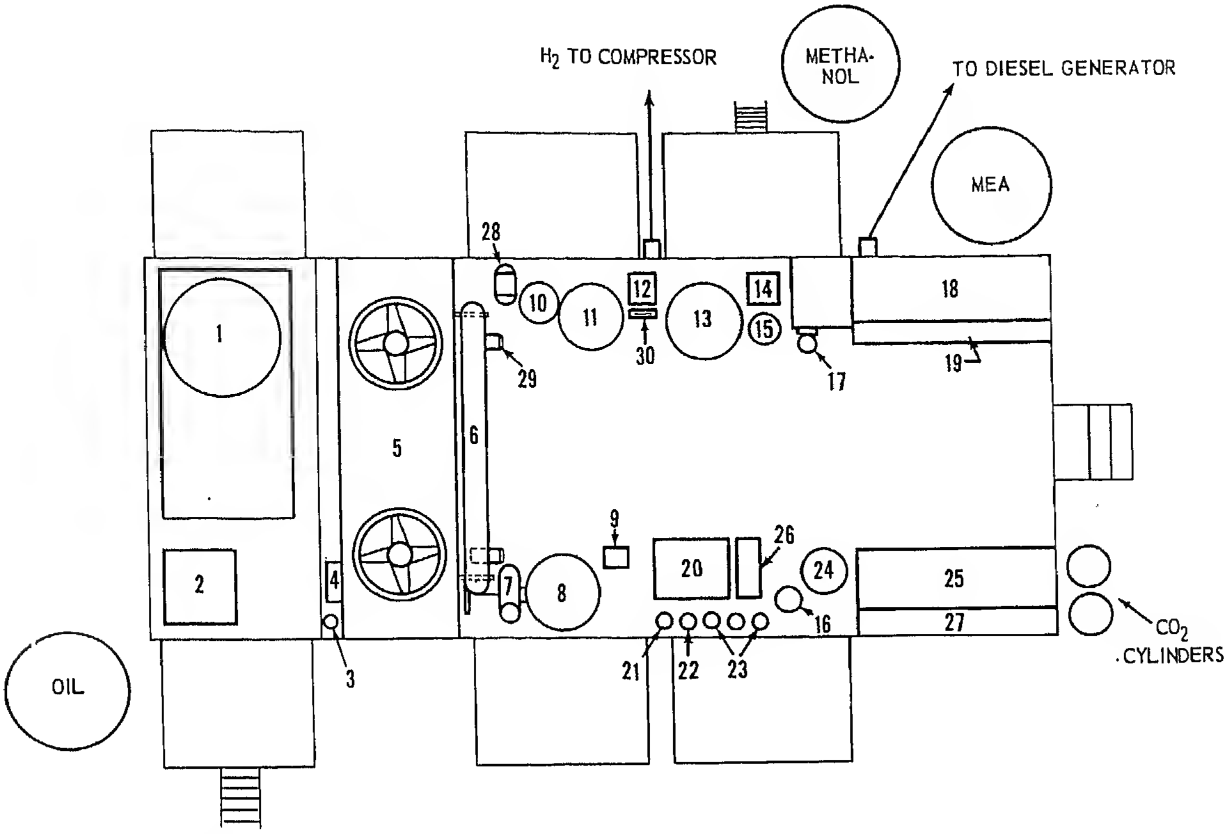
78. Equipment and Material Identification

a. Identification. The various equipment units in the mobile plants, in general, will carry some means of identification which should assist the new operator. Some plants have their piping color coded so that the personnel can readily determine the flow system for the various materials, while others have the name of the flowing material stenciled on the pipe.

b. Color Codes. Most units color code only those lines which contain fluids or gases which should be handled with some degree of caution, whereas piping which does not require a degree of caution is painted to match the surroundings. In conformance with specification Mil–Std–101–A, lines carrying flammable materials should be yellow, toxic materials brown, anesthetic materials blue, oxidizing substances green, physically dangerous materials gray, and fire protection materials red. It is recommended that operating personnel thoroughly acquaint themselves with both plant operation and equipment location before they assume responsibility for the operation of the unit. The specification Mil–Std 101–A should also be reviewed.

79. External Plant Layout

The general field arrangement for carbon dioxide and dry ice plants is shown in figure 77. It should involve the same considerations, such as water source, surrounding atmosphere, land drainage, and so on, that were covered in paragraph 47.



1 Steam boiler
2 Fuel oil tank
3 Space heater
4 Battery charger
5 Cooling tower
6 Superheater
7 Induced draft blower
8 Converter
9 Condenser separator
10 Vaporizer
11 Absorber
12 MEA exchanger
13 Reactivator reboiler
14 Condenser separator
15 $KMnO_4$ scrubber
16 Separator
17 Feed and transfer pumps
18 Makeup and storage tank
19 Panel board
20 CO_2 compressor
21 Separator
22 Filter
23 Dryer
24 Liquefier
25 Freon unit
26 Liquid pump
27 Panel and desk
28 Cooling water pump
29 Spray water pump
30 MEA pump

Figure 75. Internal plant layout for methanol-water Process.

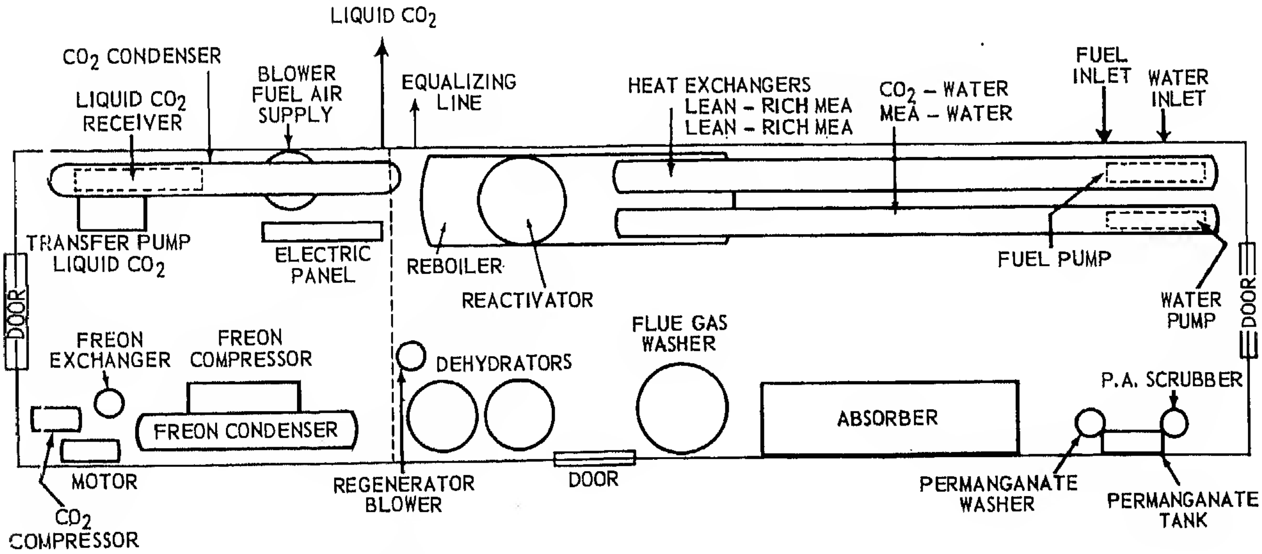


Figure 76. Internal plant layout for Girdler process.

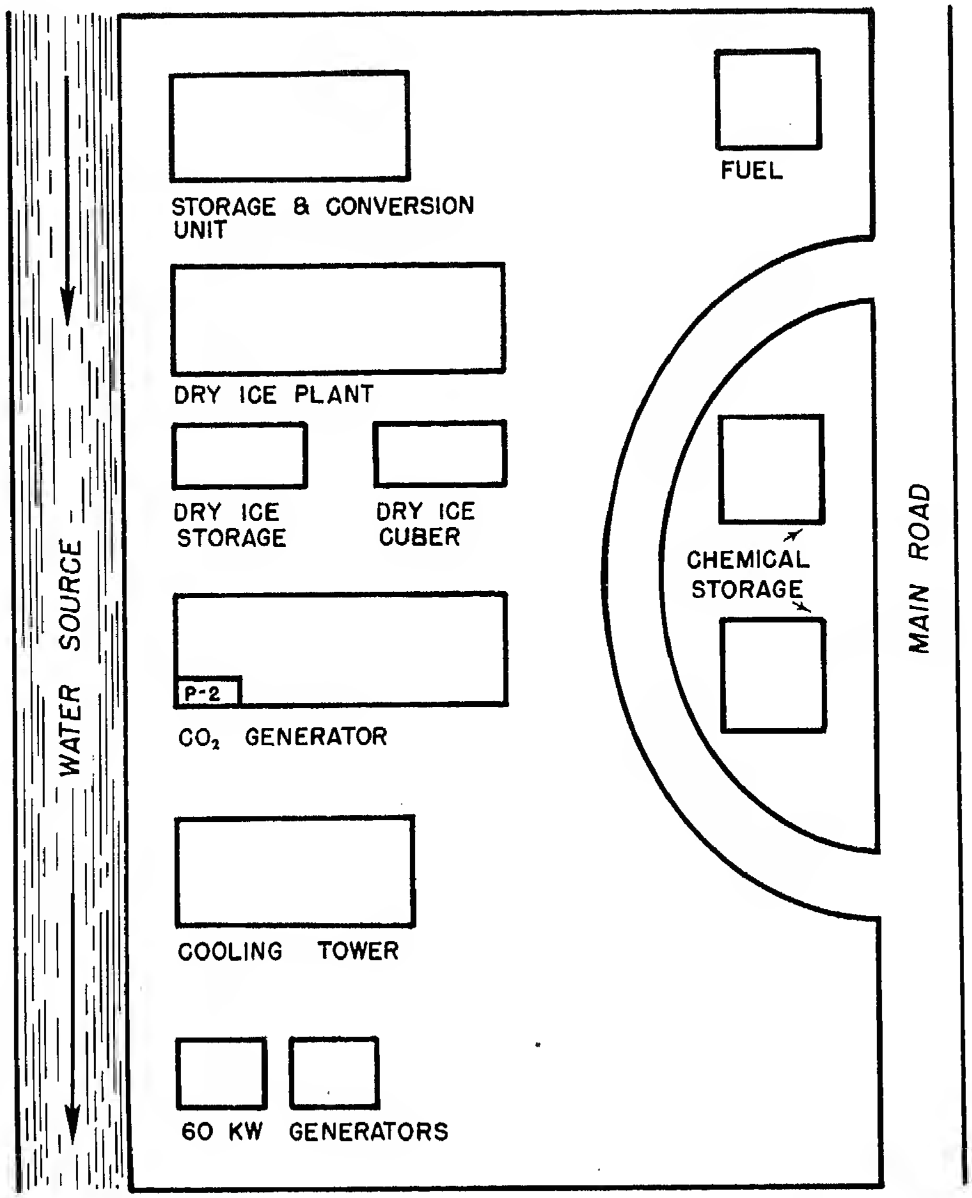


Figure 77. Field arrangement for CO_2 and dry ice plants.

Section VI. TRANSPORTATION AND STORAGE OF CARBON DIOXIDE

80. Introduction

Liquid carbon dioxide can be stored and transported in cylinders. However, because of the high vapor pressure of liquid carbon dioxide generated at comparatively moderate temperatures (1,072 psi at 30°C. (86°F.)), the cylinders used for storage and handling of the gas are of heavy-wall construction, and must be tested to withstand pressures as high as 3,000 psi. Though cylinders are used in the majority of applications (for fire extinguishers and for charging soft drinks), large quantity shipments of carbon dioxide are not practical by cylinder because of the cost and cumbersome nature of the storage container. When carbon dioxide is shipped in the solid state it is necessary that the shipping containers used maintain the dry ice at low temperatures; hence their construc-

tion and size would also prohibit the shipment or storage of large quantities of carbon dioxide. Low-pressure 2½-ton and 8-ton storage units (fig. 78) are used in conjunction with the mobile carbon dioxide gas generating plants. The units' operation and construction, as manufactured by the Cardox Corporation, are discussed in this section.

81. Two and One-Half-Ton Unit

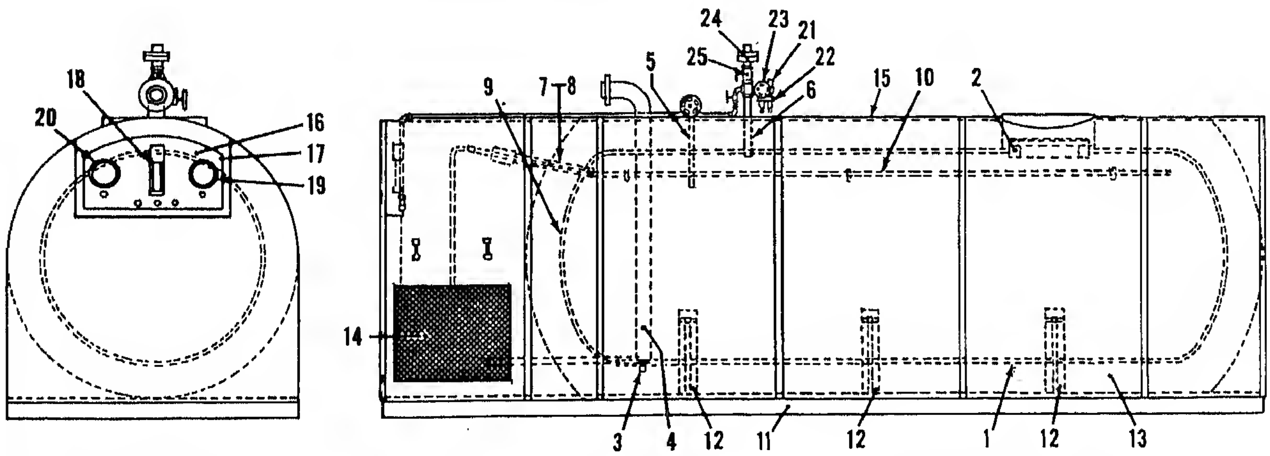
a. Operation. The 2½-ton Cardox unit is a portable unit used for the storage and transportation of liquid and solid carbon dioxide at a temperature of −18°C. (0°F.) and a pressure of approximately 300 psi. The unit is equipped with a heating unit to convert the dry ice to liquid carbon dioxide. As the name indicates, the unit can hold 2½ tons or 5,000 pounds of liquid carbon dioxide. It can be constructed with comparatively thin container walls if a temperature of −18°C. (0°F.) is to be maintained. The liquid is pumped directly from the generation unit into the storage unit where the temperature and pressure are automatically controlled.

b. Equipment. The semitrailer unit consists of a storage container, gasoline engine, refrigeration unit, cylinder filling unit, heating unit, and a panel with the necessary pressure, temperature, and liquid-level gages.

(1) *Semitrailer.* The semitrailer chassis has hydraulic and mechanical handbrakes and is specially constructed for transportation by a type M52 tractor. The semitrailer housing, equipped with doors for ready access to the equipment, is made of aluminum with removable sides and end panels. The section over the pressure vessel is also covered with aluminum plate so personnel can stand on the unit when filling the storage container with dry ice.

(2) *Carbon dioxide storage container.* The storage container is designed for a working pressure of 325 psi. It is insulated with at least 4 inches of styrofoam which has been sealed by an asphalt-type material. The refrigeration and heating coils are mounted on the inside of the pressure container under the top cover.

(3) *Refrigeration unit.* The refrigeration unit which employs freon 12 as the refrigerant keeps the carbon dioxide temperature in the storage container uniform by removing whatever heat is transferred to the carbon dioxide from the exterior through the pressure wall. Freon 12 is a nontoxic, noncombustible material both in the liquid and gaseous state, and it vaporizes and liquefies at −30°C. (−21.70°F.) at atmospheric pressure.



1–9 Tank and outlets and inlets
10 Refrigeration coil
11, 12 Iron frame and supports
13 Insulation material
14 Grill panel
15 Refrigeration housing
16, 17 Instrument panel
18 Liquid level gages
19 Pressure gage
20 Pressure control switch
21–25 Relief valve, automatic and manual control

Figure 78. Cross section view of typical Cardox unit.

(4) *Heating Unit.* The heating unit rapidly converts solid carbon dioxide to a liquid by heating Arctic-type antifreeze solution and circulating it through the heating coils in the pressure vessel. The unit is complete within itself, having a combustion chamber, automatic spark ignition, and pumps which supply the fuel and air under pressure to the combustion chamber, and circulate the antifreeze solution. Dial type thermometers and pressure gages installed on the unit facilitate proper maintenance of both inlet and outlet heater temperatures and pressures of the antifreeze solution in circulation.

(5) *Motor.* An electric motor is installed in the trailer to supply the power needed to operate the refrigeration, heating, and cylinder-filling units.

(6) *Gasoline engine.* The gasoline engine is provided for emergency use when the mobile unit is located where electric power is not available.

(7) *Cylinder-filling unit.* Most storage trailers have a cylinder-filling unit which is designed to remove liquid carbon dioxide from the storage unit and charge it into a cylinder at approximately 800 psi pressure.

(8) *Gage panel.* The control panel, mounted on the side of the housing between the two side openings, holds the liquid-level and pressure gages as well as the pressure-control and pressure-alarm switches. The liquid-level gage indicates the level of the carbon dioxide by measuring the difference of the liquid pressure between the top and bottom of the tank. The pressure gage indicates the pressure within the tank and should register approximately 300 psi.

82. Eight-Ton Cardox Unit

In contrast to the 2½-ton unit, the 8-ton Cardox unit is used only for the storage and transportation of *liquid* carbon dioxide. In addition to its larger capacity, 8 tons or 16,000 pounds of liquid carbon dioxide, this unit differs from the 2½-ton unit in that it does not have the heating unit and is not equipped to convert dry ice into liquid carbon dioxide. Since the pressure vessel, refrigeration unit, gasoline engine, electric motor, cylinder-filling unit, gages, and controls on the units are identical, the foregoing discussion of the 2½-ton Cardox unit applies to the 8-ton unit with the above exceptions.

83. Conversion and Storage Trailer

The Cardox trailer is a completely self-contained unit designed for road movement by means of a 5-ton M52 tractor. It is primarily made for the storage and transportation of liquid carbon dioxide, and the conversion of solid carbon dioxide into a liquid. It can hold 8½ tons of liquid carbon dioxide. It measures 26 feet long, 10 feet high, 8 feet wide, and weighs 7½ tons empty (fig. 79).

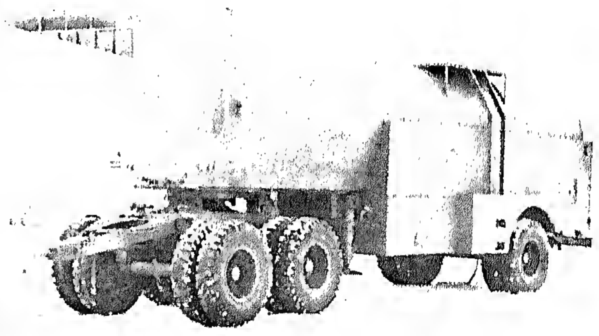


Figure 79. Cardox unit.

84. Summary

In the foregoing sections, all phases of the generation and storage of carbon dioxide presently in use by the Army have been discussed. They can be outlined as follows:

a. Carbon Dioxide. Carbon dioxide can be generated by one of two methods:

(1) Using a methanol and water solution.

(2) Using flue gas from which carbon dioxide is absorbed.

b. Pure Carbon Dioxide. The pure carbon dioxide obtained from plants using either of these two methods can then be—

(1) Charged directly into cylinders.

(2) Passed into the solidifying plant to be converted to dry ice which can be—

(a) Used in the solid state at the site.

(b) Loaded into a Cardox unit for transportation and reconversion to liquid carbon dioxide.

(c) Loaded into 1-ton insulated storage and transport containers.

(3) Passed into the Cardox units in the liquid state for transportation or storage and ultimate use.

Section VII. PRODUCTION OF CARBON DIOXIDE AND HYDROGEN BY THE METHANOL-WATER PROCESS

85. Basis

As previously outlined in paragraphs 63 and 64, the methanol-water process as shown in the flow sheet (fig. 80) is based primarily on the catalytic conversion of the vaporized methanol-water mixture to obtain carbon dioxide and hydrogen.

86. Feed System

The purpose of the feed system, as shown in figure 81, is to prepare the methanol and water mixture for the gas-generating system. The feed system is composed primarily of the feed storage tank, the feed makeup tank, the methanol drum and pump, and the feed pump. To prepare the feed, methanol is added to the makeup tank by pumping it from the methanol drum. After the proper amount of methanol has been added, distilled water obtained from the condensate cooler is added to the makeup tank through a three-way valve. The mixture is then circulated in the makeup tank to insure a uniform solution. A test sample is then drawn, and if the mixture is of correct concentration, it is transferred to the storage tank. The methanol-water solution feed is now ready for use in the system.

87. Gas Generation System

The purpose of the generation system (fig. 82) is to convert the methanol-water mixture into carbon dioxide and hydrogen. The principal components of the generation system in-

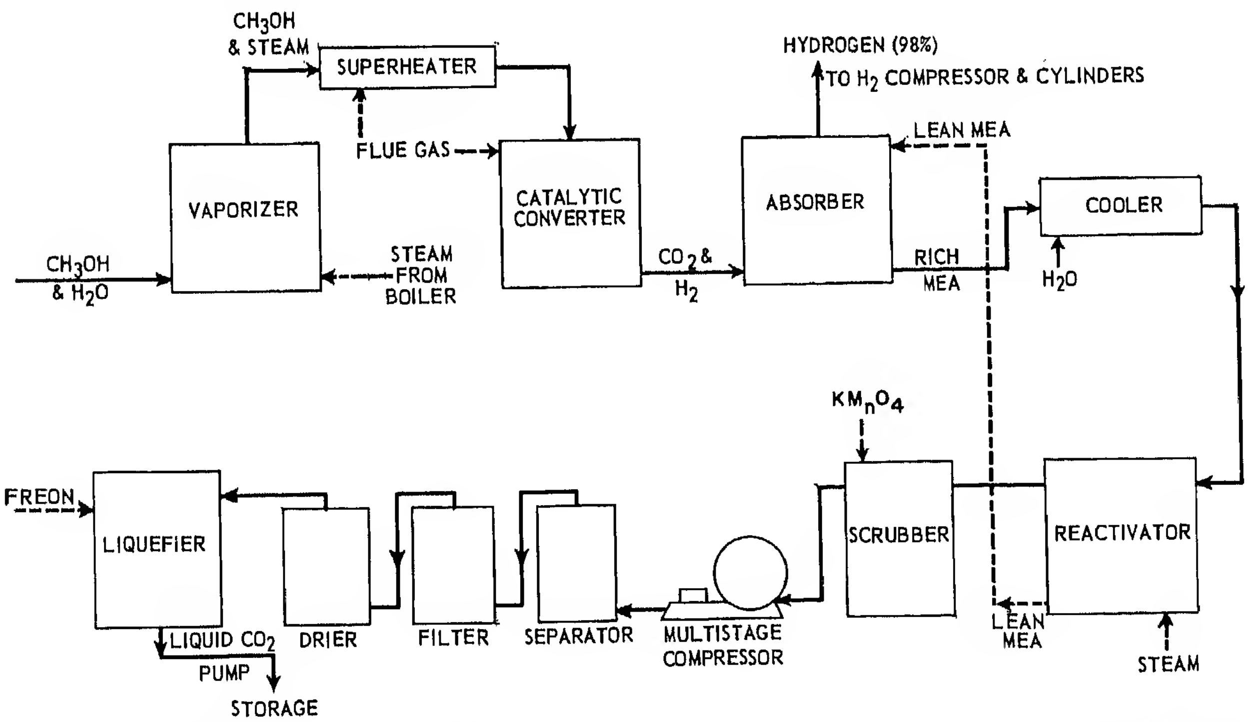


Figure 80. Simplified flow sheet for generation of carbon dioxide and hydrogen by the methanol-water process.

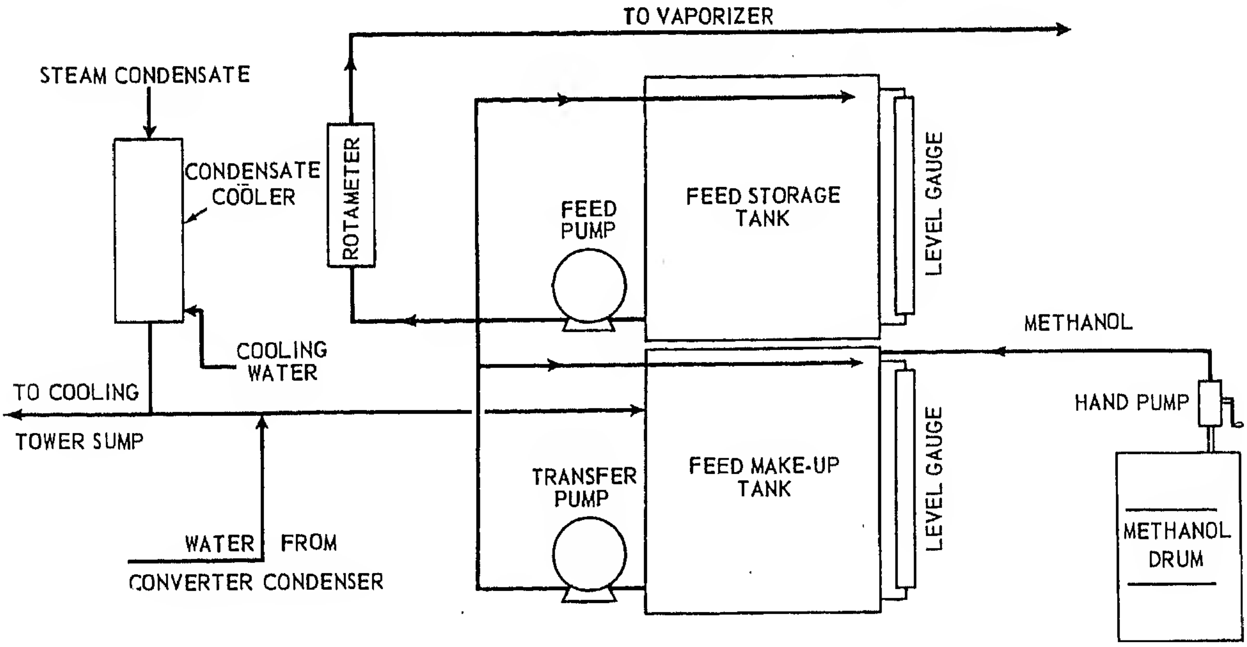


Figure 81. Feed system for the methanol-water process.

clude the vaporizer, the catalytic converter, the superheater, and the condenser.

a. Vaporizer. From the storage tank the methanol-water feed passes into the vaporizer. In the vaporizer, the methanol-water solution is passed over steam coils in the boiler and the latent heat of the steam causes the methanol-water solution to vaporize. The vapor then rises to the top of the vaporizer and into the superheater. The vaporizer generally operates at approximately 20 psig pressure.

b. Superheater. In the superheater the vapor is further heated by the flue gas from the vaporizer boiler to an approximate temperature of 302°C. (575°F.). The high temperature is necessary to convert the vapor into carbon dioxide and hydrogen in accordance with the reaction shown in paragraph 63.

c. Catalytic Converter. The vapor is drawn from the superheater into the top of the catalytic converter. Here the vapor mixture is converted into carbon dioxide and hydrogen and a small amount of carbon monoxide. The converter is operated with an excess amount of water to insure a favorable chemical reaction.

d. Condenser. The gaseous mixture and entrained steam now pass through the condenser which condenses the steam. Since the trap for the condensed water will contain traces of unreactive methanol, the condensed water is returned to the feed makeup system rather than being sent back to the water sump.

88. Gas Separation System

Figure 83 shows the gas separation system which separates the gases from each other. The system consists primarily of the MEA absorber, the MEA exchanger (cooler), the reactivator, the condenser, the potassium permanganate scrubber, and the carbon dioxide separator. This is sometimes called the cyclic system because the MEA is circulated through all components involved over and over again. During each cycle the temperatures and pressures are changed to produce conditions that are most conducive to, first, absorption, then separation.

a. The MEA Absorber. The mixture of hydrogen and carbon dioxide enters the bottom of the absorption tower. A 30-percent solution of MEA is fed into the top of the tower countercurrently to the gaseous mixture. As the two come into contact with each other, the MEA absorbs the carbon dioxide and is pumped through the bottom of the tower, while the free hydrogen (of 98-percent purity) is removed through the top of the tower and passes through a separator. The separator removes any additional water that might be entrained in the gas. The

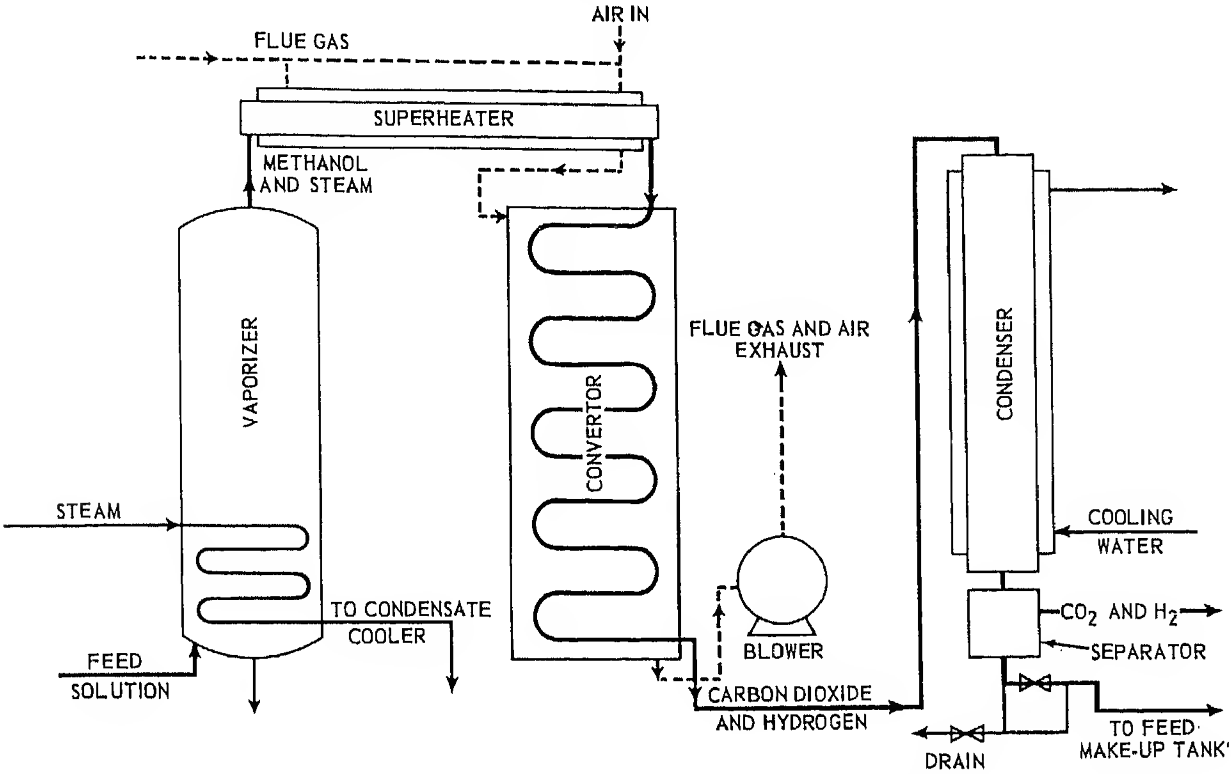


Figure 82. Generating system for methanol-water process.

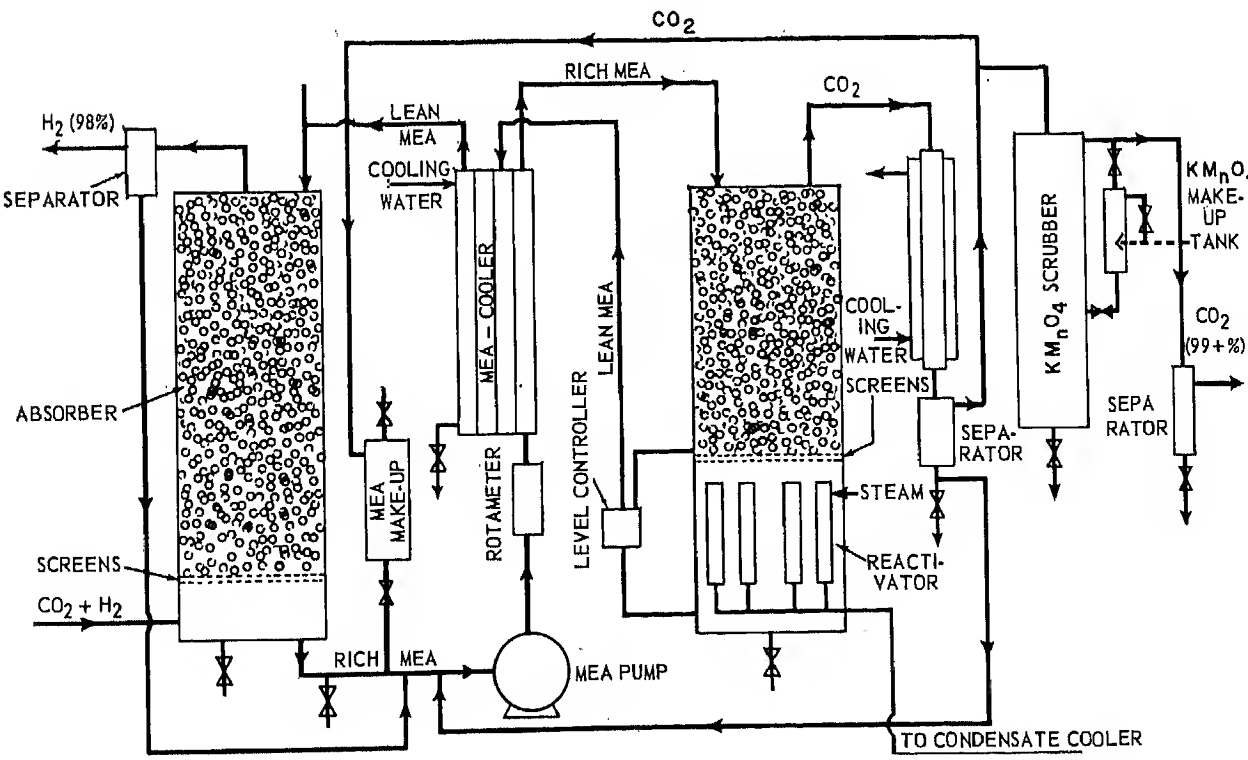


Figure 83. Separation system for methanol-water process.

hydrogen is then compressed to the cylinder manifold pressure and fed into the manifold for cylinder charging. To avoid the possibility of explosion within the absorber, a back pressure regulating valve is installed in the outlet H_2 line to keep 5 psig on the gas generation system, thus preventing air from entering the system which would cause an explosion.

b. MEA Exchanger. The MEA and carbon dioxide solution, which is now referred to as rich MEA, is filtered and passes into a heat exchanger which preheats the solution in a preliminary step to the separation of the MEA and carbon dioxide.

c. Reactivator. The reactivator is a packed column in which the rich MEA from the heat exchanger is vaporized by steam flowing through the reboiler tubes in the bottom of the column. The temperature of the reboiler is such that the mixture entering the reactivator reaches a temperature of 144°C. (290°F.) and a pressure of 40 psig. At this temperature the MEA and carbon dioxide dissociate and as the hot vapor travels upward through the column, separation is achieved. As a result the carbon dioxide passes through the top of the column to a condenser and the MEA is removed from the bottom of the column. The MEA flowing from the bottom of the reactivator column is now known as lean MEA and is fed back through the preheater (MEA exchanger) to heat the rich MEA. The term "rich" indicates MEA that contains carbon dioxide and "lean" indiactes MEA that does *not* contain carbon dioxide. The lean MEA is further cooled by water and fed back into the top of the absorption tower. Any of the MEA lost in this transfer process is compensated for by the MEA from the makeup tank.

d. Condenser. The carbon dioxide, together with some vaporized MEA and water, flows from the reactivator to a condenser where the MEA and water condense and are fed back into the system at a point prior to the MEA exchanger.

e. Scrubber. From the condenser the carbon dioxide is bubbled through a potassium permanganate scrubber which removes any further traces of impurities in the gas. The gas then passes to a separator where any additional entrained liquid is removed and the pure carbon dioxide flows to the carbon dioxide system.

f. Flow Rate. The normal flow rate is established to maintain operating levels and will vary considerably between start-up and productive operation. The following rule of thumb, developed through practical experience, has proven successful in establishing the correct flow rate. "The flow rate in gallons should be approximately equal to one half of the reboiler pressure."

89. Carbon Dioxide System

The purpose of the carbon dioxide system (fig. 84) in the methanol-water unit is to liquefy by compression and cooling the carbon dioxide obtained from the separation system. This makes it possible to pump the liquefied gas into the cylinders or to convert it into the solid state in the dry ice plant. This system consists of a multistage compressor, usually two stages with an intercooler and after-cooler built integrally into the compressor, a separator, a filter, a dryer, and a liquefier.

a. Compressor. Initially carbon dioxide from the separation system passes through a secondary filter to insure the removal of any liquid entrapped in the gas. The gas then enters the first stage of a two stage compressor at an inlet pressure of 35 psig. This pressure is maintained back through the potassium permaganate scrubber and reactivator by recirculating some of the high-pressure gas from the discharge side of the compressor through these two pieces of equipment, which are a part of the gas-separation system. It is necessary to maintain this pressure in the reactivator to insure that the required temperature for adequate reactivation of MEA solution is held. From the first stage of compression the gas passes through an intercooler to remove the heat of compression, and then into the second stage of compression where the pressure is raised to approximately 300 psig. The heat resulting from the second stage of compression is removed in the aftercooler.

b. Separator. The gas from the compressor then enters a separator which removes the water (condensed out of the gas by the aftercooler) and oil (picked up from the compressor).

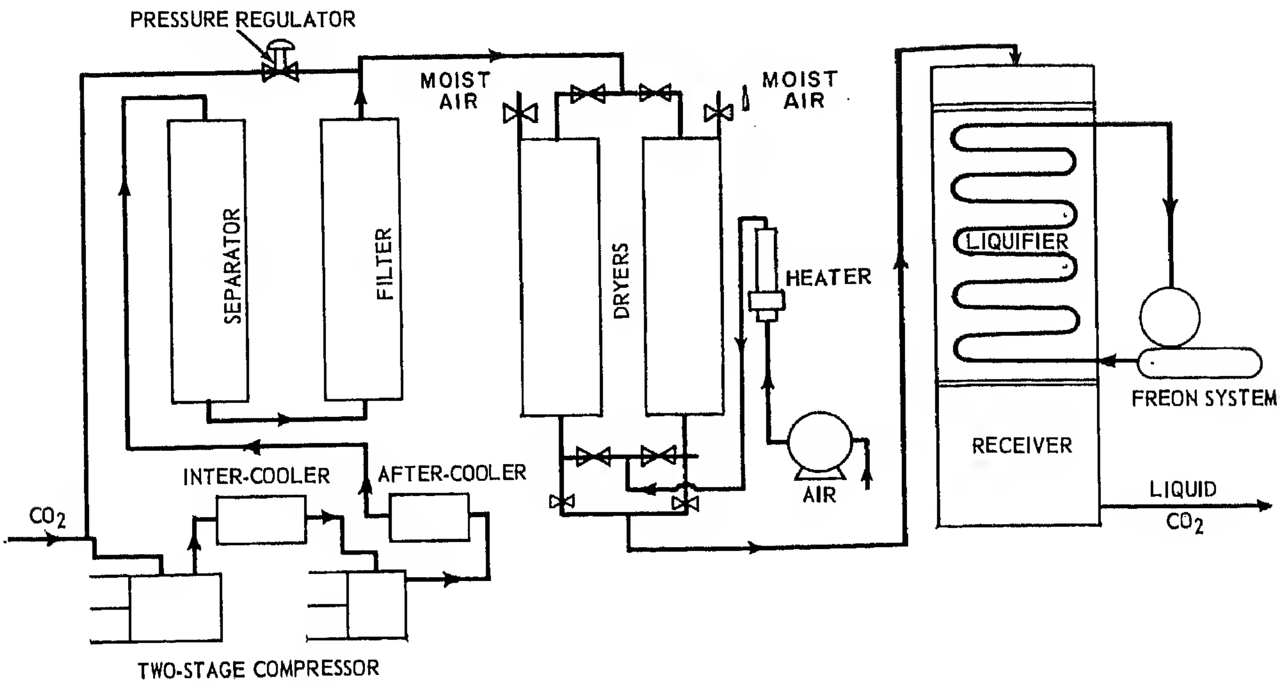


Figure 84. Carbon dioxide system for methanol-water process.

c. Filter. The gas next enters a cylinder filled with activated alumina which acts as a filter to remove any additional traces of entrained oil.

Note. If the MEA turns slightly darker than normal during operation, it is generally a sign of dirty filters. Fine particles of soot will work through the filter mesh and contaminate the entire system unless the filters are cleaned.

d. Dryer. After passing through the filter, the gas is piped into the top of 1 of 2 cylinders (called adsorbers or dryers) which are filled with activated alumina and are designed to adsorb any water still in the gas. These cylinders are alternately reactivated (dried out) by passing heated, thermostatically controlled air across the alumina.

e. Liquefier. The dry carbon dioxide now enters the liquefier where it is converted to the liquid state by the use of a refrigerant such as freon. The liquid carbon dioxide collects in the bottom portion of the liquefier called the receiver. The liquid carbon dioxide flowing into the receiver is pumped to the charging manifold and then into the carbon dioxide cylinders that are located on a scale to indicate when the cylinder has the proper charge. The entire unit can also be attached to the dry ice plant, and the liquid pumped directly into the storage tank of the plant for conversion into solid dry ice.

90. Water Distribution System

a. Equipment. A cooling tower and a water makeup tank (fig. 85) are the main items of equipment in the water-distribution system.

b. Cooling Tower. The cooling tower is the heart of the water system. It removes heat from the process through heat exchangers and supplies water to the boiler for the generation of steam. Water from the condensate traps formerly used in the heat exchanger, as well as the water overflowing from the boiler, enters the cooling coils of the tower as shown in figure 85. This water inside the coils is cooled by water at a lower temperature flowing over the coils. The water temperature flowing over the cooling coils in the cooling system is lowered through contact with the cooling system is lowered through contact with the cooler outside air, and partial vaporization of the water into the air which, in the process, absorbs some of the latent heat of the parent liquid. For further information, refer to paragraphs 71 and 72.

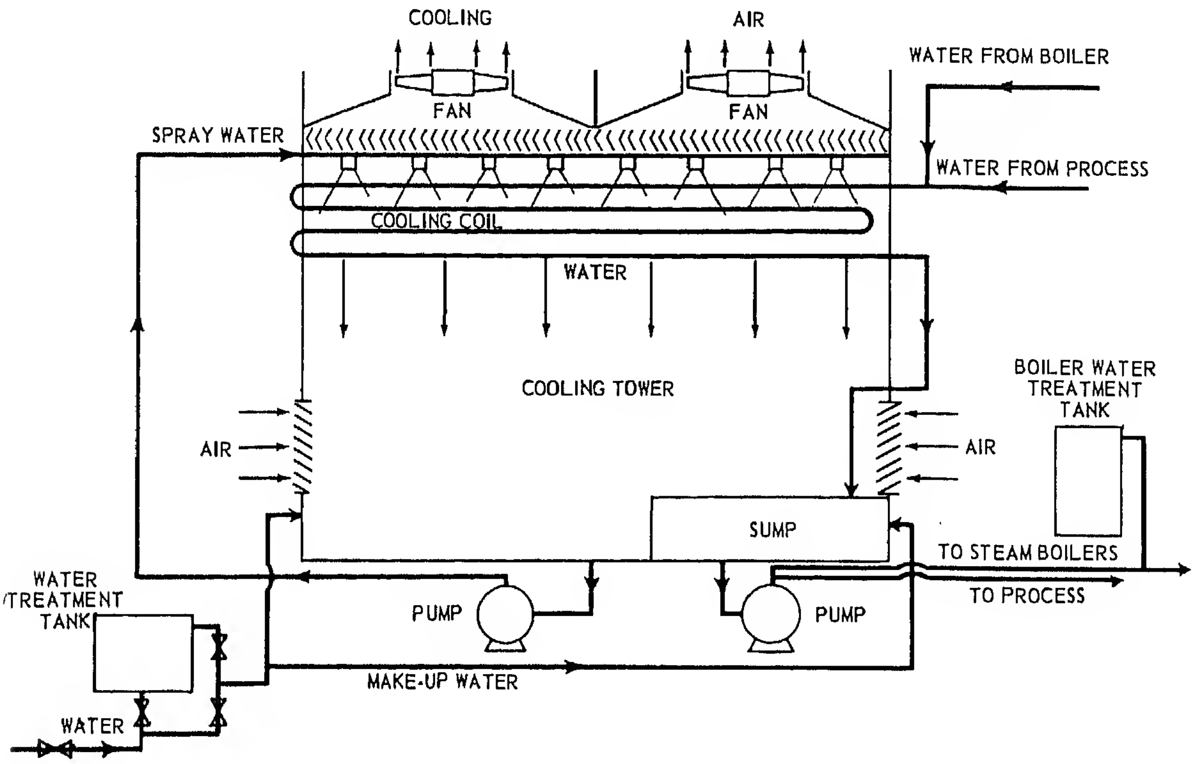


Figure 85. Cooling system for methanol-water plant.

91. Heating System

The heating system furnishes process steam; flue gas for the superheater and converter; steam to make distilled water for the feed solution; and it also provides heat in the trailer for the comfort of the personnel. Briefly, steam is provided by vaporizing water in the coils of the boiler. The heat to perform this task is furnished by an oil-fired burner which feeds an oil mixture into the system in proportion to the amount of water in the boiler coils. The amount of water that enters the boiler is controlled by a pressure switch at the boiler outlet. If the steam pressure reaches a predetermined point, the pressure switch actuates a valve to automatically bypass the water back to the boiler water feed. Simultaneously this safety mechanism automatically bypasses the oil to the burner until the water flow is restored in the system. Under normal operating conditions, however, the consumption of the steam in the system should never allow this condition to occur.

Section VIII. SAFETY AND PROTECTIVE MEASURES

92. Introduction

The plants used in this process are well protected against any dangerous conditions which might develop in the course of their operation. Safety valves, safety heads (on converters to relieve pressure resulting from internal explosion), alarm systems, or a combination of these serve as a constant guard against malfunctioning equipment or abnormal pressure rises in the system. In addition, a central control panel with sufficient instruments provides information on temperature, pressure, or flow conditions at key points in the system's operation. The motors which serve as power sources in the plants are totally enclosed for protection against sparking which would ignite the flam-

mable materials being generated or used. The motors in the carbon dioxide plant are equipped with overload safety devices that must never be blocked or bypassed. Portable carbon dioxide fire extinguishers (fig. 59) are available for emergency use in the plant areas where there is a fire hazard.

93. Handling Materials Used in Production

a. Methanol. Methanol used in the gas-generating plants discussed in this chapter is poisonous, volatile, and flammable, and methanol vapor forms explosive mixtures with air. Consequently, be careful in handling or transferring the liquid. Areas used for these operations should be well ventilated and protected from sparks or flames. If any methanol should spill on the floor of the trailer, wipe it up immediately and dispose of the rag by placing it in a closed metal container or by burying it. Never mix methanol and oily rags.

b. Monoethanolamine. MEA and its solutions are chemical bases which are highly corrosive and hazardous to personnel. When handling or transferring MEA from its container to the generating plant, wear safety goggles to protect the eyes, and use extra care to avoid splashing the solution on hands or face. If any solution spills on the skin, immediately irrigate or flood the area with water since speed is essential in preventing serious caustic burns. Do not wipe or rub as this will spread the contaminant over a larger area and, if it is on the skin, will cause irritation. MEA also attacks common clothing materials, so take care in handling to prevent spilling on clothing or the cloth will rot away.

c. Catalyst. In the gas equipment plant, the reduced catalyst is a fire hazard because it oxidizes rapidly, generating enough heat to ignite any flammable material with which it comes into contact. Consequently, in discharging the converter, dump the catalyst into a metal container, thoroughly wet down, and dispose of it by dumping into water or burying.

d. Permanganate. Potassium permanganate and glycerine must never be allowed to contact each other. The result is instantaneous combustion or explosion. This will happen whether the KM_nO_4 is dry, crystalline, or in a water solution. Contact between permanganate and other organic materials may also cause combustion or an explosion. Therefore, the container used for the measure and transfer of permanganate will be used for this purpose only. If either the dry chemical or the liquid is spilled, immediately flush the area with water.

94. Gas Products

a. Hydrogen.

(1) *Hazards.* Hydrogen mixed with air is highly explosive and whenever possible operate the plant with all doors and hatches open to insure adequate ventilation. Make frequent checks to insure that there is no leak of hydrogen from the piping or equipment. Also, avoid all flames or sparks which might ignite an explosive mixture. There should be no smoking within a 100-foot radius of the plant while it is in operation. Do not wear shoes with nails, and use only nonferrous, nonsparking tools such as brass or bronze hammers, wrenches, screwdrivers, and so on. When purging a hydrogen gas stream, vent it to the air.

(2) *Safety rules.* The same safety rules apply to hydrogen as apply to acetylene except that pressure over 15 psi may be used. These rules are covered in detail in paragraph 120. Since hydrogen leaks through all but the best fittings, use special care to guard against leakage. Use soapy water with a 100 percent pure olive-oil base in testing for leaks.

b. Carbon Dioxide.

(1) *Hazards.* Cabon dioxide can either be stored as a liquid under pressure in cylinders or be vapor-flashed to snow and then compressed into blocks or cubes and stored as dry ice. Dry ice does not melt but changes directly from the solid back into a gas. One pound of ice will produce about 9 cubic feet of carbon dioxide gas at ordinary temperatures. The principal hazards of carbon dioxide are its asphyxiation characteristics and storage pressure.

(2) *Safety rules for liquid carbon dioxide.*

(*a*) Since carbon dioxide, in addition to being heavier than air, is both invisible and odorless, it presents a particular hazard. It tends to collect in low, unventilated places. Persons going into such areas, or remaining there, run the risk of smothering to death, unless they are equipped with a breathing mask and an independent supply of oxygen. Small percentages of carbon dioxide will cause tiredness and headaches. Three percent in air doubles the breathing effort, 5 percent causes panting, 8 percent causes marked distress, and 10 percent causes unconsciousness.

(*b*) Treatment of an exposed person includes removing him from the carbon dioxide atmosphere, using artificial respiration, administering oxygen, and keeping him warm and quiet.

(*c*) Avoid artificial heating of cylinders whenever possible. Never use electric or gas heaters. If an increased discharge rate is required, immerse the cylinder in a bath of lukewarm or 50°C. (120°F.) water.

(*d*) Do not expose cylinders to marked changes in temperature (exterior —18°C. (0°F.) to interior 21°C. (70°F.)), since the gas may expand sufficiently in this change to break the rupture disk and injure nearby personnel with flying particles.

(*e*) Be careful in preventing any foreign material, particularly water or water vapor, from entering the cylinder valve because of the danger of freezing and clogging the valve.

(*f*) Never use carbon dioxide in bottling plants without reducing the pressure through a suitable regulator attached to the cylinder.

(*g*) Weigh cylinders before any gas is withdrawn and again after recharging the system. Record the two weights. The difference will be equal to the weight of the gas that has been withdrawn. Follow this weighing and recording procedure each time gas is discharged from the cylinder, so that the quantity of gas remaining may be learned at any time by referring to the records. In this way, partly full cylinders will not be confused with the empties.

(*h*) All electrical controls and motors are potentially dangerous if allowed to become wet with water or liquid chemicals. A combination of wet hands, clothing, and electrical equipment can induce current flow through the body to the metal floor of the plant. Painful shock, or even death by electrocution, could result.

(*i*) In operating the scrubber, never allow potassium permanganate and glycerine to come into contact with each other. The result would be instantaneous combustion or an explosion.

(3) *Safety rules for solid carbon dioxide (dry ice).*

(*a*) Wear gloves when handling dry ice or materials that have been in contact with dry ice since the ice has a temperature of —79°C. (—110°F.) and can cause frostbite similar to a severe burn.

(*b*) Do not put dry ice in any drink as even a small piece will cause a painful frostbite.

(*c*) Do not place dry ice in any tight container except one designed for the purpose since the pressure associated with its sublimation (evaporation) characteristics can cause an explosion.

(*d*) When dry ice is cut, make sure the saw guards are in place and a wooden strip used to push the ice against

the saw blade to prevent personnel injury.

(*e*) In a small enclosed space, gas from dry ice acts the same as liquid vapor, causing suffocation. If warned by quickened breathing, dizziness, or ringing in the ears, get into fresh air immediately.

95. Fire Fighting

See paragraph 52.

CHAPTER 4

GENERATION OF ACETYLENE

Section I. INTRODUCTION

96. Acetylene

Acetylene is a colorless gas which is slightly lighter than air. In its pure state it has a garlic-like odor and is slightly anesthetic. The production of acetylene is similar to that of carbon dioxide and unlike oxygen in that it is obtained by a chemical process reaction. Acetylene differs from oxygen, hydrogen, and carbon dioxide in that it is classed as an organic rather than an inorganic compound. It will be recalled from the discussion in paragraph 6 that organic chemistry is generally referred to as the study of the chemistry of carbon compounds; and although the dividing line between organic and inorganic compounds is not a sharp one, acetylene, which has the chemical formula of C_2H_2, can be expected to exhibit some of the more common properties associated with an organic material. When it is produced by the calcium-carbide-water process, it contains some impurities. The plant used by the Corps of Engineers employs the carbide-water process and is called an acetylene generator. The manufacturer's operational manual calls it the TMCP–750, which stands for Trailer Mounted Compression Plant, 750 cubic feet per hour.

97. Uses of Acetylene

The most important use of acetylene gas is in the oxyacetylene cutting and welding torches for cutting and welding metals. Acetylene has also been used for lighting purposes, though its applications in this area have been materially reduced since the advent of the incandescent lamp. Some miners' lamps still use acetylene and some lighthouses continue to use it because of its brilliance. However, its explosive nature is a major disadvantage for these applications. One of the more recent uses for acetylene is as a raw material in the manufacture of other compounds such as synthetic rubber. If its cost were not so high, acetylene would be used more extensively in this respect.

98. Sources of Acetylene

Most of the acetylene produced today is formed by the reaction of water and calcium carbide, a chemical compound consisting of 1 atom of calcium and 2 atoms of carbon. On occasion, acetylene has also been produced by subjecting carbon compounds such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8), and natural gas to a process called thermal decomposition. In this process high temperatures break down the bonds holding the large hydrocarbon molecule together and cause it to reform into different, smaller hydrocarbon molecules usually producing some hydrogen and free carbon. Because the carbide process is used by the Army for the mobile gas generating units, it will be described in greater detail in this chapter.

99. Properties of Acetylene

Whenever acetylene has a disagreeable odor, it appears to be due to traces of impurities. Physiologically, acetylene acts as an anesthetic and the purified gas has been used for this purpose. As stated previously, it is an organic compound containing 2 carbon and 2 hydrogen atoms. The bond holding the carbon atoms is extremely unstable, and as a result acetylene is dangerously explosive. When mixed with oxygen, acetylene burns with a flame hotter than any other gas known. This fact alone is responsible for the wide use of acetylene in welding torches. In any atmosphere containing

more than 2.5% acetylene, the acetylene is explosive. Though oxygen is necessary for combustion it is not necessary in an acetylene explosion, because this is caused by decomposition. Thus acetylene must be handled with utmost care and can at no time be allowed to escape into a confined atmosphere. Being lighter than air, it will tend to collect at the top of a room, or trailer, and form an explosive mixture. In addition to its wide explosive range, acetylene is dangerous at any pressure above 15 psig. However, if properly controlled the pressure of small quantities of acetylene may be raised to enable faster filling of cylinders. Also, this explosive characteristic of acetylene gas makes it necessary to store the material in a manner different from all other gases. Details on the construction of acetylene cylinders, filler materials, and the absorbing agent, acetone, used in the storage of acetylene under pressure are given in paragraph 130.

100. Properties of Calcium Carbide

a. Manufacture. Calcium carbide is the major raw material in the production of acetylene. It is a hard, grey, solid substance that is produced by heating lime (calcium oxide) and coke (carbon), at a ratio of 60 to 40 by weight, by means of an electric furnace. A 3-phase electric current is passed through carbon electrodes (or rods) extending into the furnace and heats the mixture to between 2,000° and 2,100° C. (3,600° and 3,800° F.). At this temperature the calcium oxide and coke are fused together to form calcium carbide and carbon monoxide. This action can be represented by the following equation:

$$CaO + 3C \rightarrow CO + CaC_2$$

The molten calcium carbide is allowed to cool, and, after solidifying, is crushed and screened into various sizes. The carbide is, so sensitive that the crushing and screening operation is carried out in a nitrogen atmoshpere to prevent the moisture in the air from combining with the carbide and forming an explosive mixture of acetylene and air in the area.

b. Chemical Properties. The most useful chemical property of carbide is its ability to react with water and form acetylene. For this reason the carbide is supplied in airtight leakproof drums which can be readily handled or stored. A leaky carbide drum is easily detected by a characteristic acetylene odor and the gray deposit formed inside the drum as the result of the interaction of calcium carbide and water vapor. If a leaky drum is found and another airtight drum is not readily available for storing the carbide, the material should be discarded by dumping very small amount (handfuls) into a pit where the acetylene plant waste products are discarded.

101. Properties of Calcium Hydroxide

The byproduct of acetylene generation is calcium hydroxide ($Ca(OH)_2$), commonly known as lime slurry and resembling a mixture of whitewash. It is common for small carbide particles to become entrained in the slurry as it leaves the plant. These particles continue to react and produce acetylene. Th lime is an active base as indicated by the (OH) radical in the formula, and is practically insoluble in water. It has a characteristic acetylene odor, and is formed as a residue in the acetylene generator from the action of water on the calcium carbide. It is commonly disposed of by digging a pit near the mobile unit and draining the lime residue into it for storage and possible future use.

Section II. CHEMISTRY OF ACETYLENE PRODUCTION

102. Introduction

The reaction of calcium carbide and water is used in the mobile gas-generating units to produce acetylene. This method can be expanded even further by breaking it down into a carbide-to-water and water-to-carbide process. In the carbide-to-water process, the carbide is added to a relatively large amount of water, producing acetylene and leaving a thin mixture of lime (calcium hydroxide) which is approximately 90 percent water. In the water-to-carbide process, a limited amount of water is added t the carbide and the heat from the reaction used to vaporize the excess water. In t latter process there is less calcium hydra waste, but it requires careful, precise contr

of the temperature and pressure. Consequently, for general application in the services, the Army has standardized on a mobile generating unit which uses the carbide-to-water process.

103. Chemical Reactions

Acetylene is produced from calcium carbide and water by carefully controlling the following reaction:

$$CaC_2 + 2H_2O \rightarrow \underset{\text{Gas}}{C_2H_2} + Ca(OH)_2 - 139{,}100 \ \frac{\text{CAL}}{\text{GM-Mol}}$$

This chemical formula states that 1 molecule or mole of calcium carbide reacts with 2 molecules of water to produce 1 molecule or mole of acetylene and 1 molecule or mole of calcium hydroxide. Recall that a gram mole of a compound is the number of grams equal to the sum of the atomic weights of the individual elements. By an examination of table I the atomic weights of the elements are found to be—

Calcium	40.080
Carbon	12.011
Oxygen	16.000
Hydrogen	1.008

Thus, a gram mole of calcium carbide (CaC_2) is 64 grams; a gram mole of water (H_2O) is 18 grams; a gram mole of acetylene (C_2H_2) is 26 grams; and a gram mole of calcium hydroxide ($Ca(OH)_2$) is 74 grams. Therefore, it requires 64 grams of calcium carbide and 36 grams of water to produce 26 grams of acetylene. In addition, 74 grams of calcium hydroxide slurry are realized as a byproduct. A comparison of relative weights of materials, products, and byproducts is shown below.

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 - 139{,}100 \ \frac{\text{CAL}}{\text{GM-Mol}}$$

$$64 \text{ gm} + 36 \text{ gm} \rightarrow 26 \text{ gm} + 74 \text{ gm}$$

Also, for every 26 grams of acetylene produced, 139,199 calories of heat are given off. Since a calorie is the amount of heat necessary to raise 1 gram of water 1° centigrade, it can be seen that the reaction of generating acetylene is a violent and dangerous process requiring constant vigilance by operating personnel.

Section III. PRODUCTION OF ACETYLENE

104. Introduction

a. The carbide process for the manufacture of acetylene can be broken down into four distinct steps consisting of—

(1) Adding carbide to water.
(2) Collecting the generated gas.
(3) Compressing the gas into cylinders.
(4) Disposing the lime residue remaining in the generators.

b. This section, with the aid of a flow sheet (fig. 86), will trace in greater detail the process outlined in *a* above.

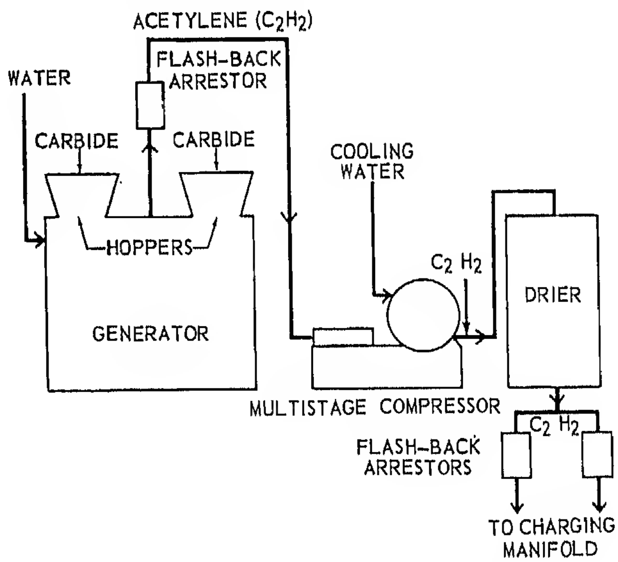


Figure 86. Simplified flow sheet for the generation of acetylene.

105. Starting the Unit

a. Prestart Procedures. Electrical power for the acetylene plant is generated by a diesel-engine-driven alternator. Before starting the alternator set, an inspection should be made for leaks, cleanliness of the area, and the presence of unnecessary material. Check the crankcase for proper oil level; check the radiator, fuel tanks, batteries, air cleaner, oil cups, and the fire extinguishers. All switches on the panel board must be placed in a start-up position. After warmup, position the switches for normal operation.

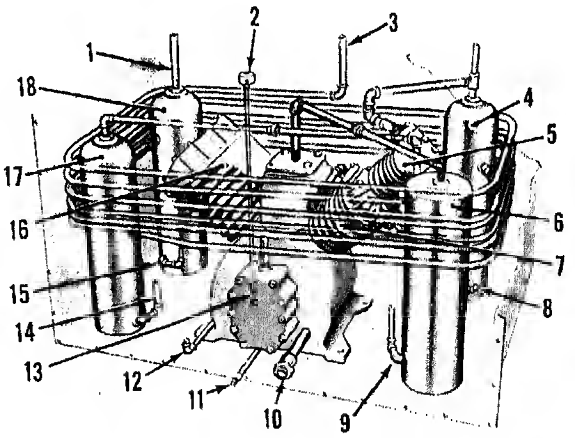
b. Start Up. Detailed instructions for starting the power plant are on the operating instruction plate, located on the left wall of the trailer just inside the door. When starting the unit, water from a river, lake, or other convenient source of supply is pumped into a water storage tank. Some of the water from the storage tank is pumped into the acetylene generator until the generator is at the operating level. Depending upon the size of the generator, the appropriate amount of calcium carbide is then charged into the carbide hoppers, which are located above the generator. After purging the entire system of air, the actual generation process is begun.

106. Generation of Acetylene

Initially, the carbide is manually fed through the throat of the hopper, and on contact with the water in the generator the actual generation of the acetylene is noted by the violent bubbling action in the water. As the reaction proceeds and more gas is generated, the pressure will build up in the generator. When this pressure reaches a predetermined point, which will vary according to operating conditions and the type of unit, the manual-feeding operation is no longer required. The feeding of the appropriate amount of carbide is now done automatically. The generated gas is drawn off through the top of the generator and at this point is referred to as low-pressure acetylene. The low-pressure acetylene then passes to a device known as a flash-back arrester. The purpose of this device is to prevent any flame or spark which may occur in the remainder of the process from reaching the generator. The flash-back arrester is designed so that the acetylene has to bubble through a tank of water, and the water stops any flame or spark from flashing back to the generator. The acetylene is then filtered to remove any dirt and free water it has picked up, and is passed to the first stage of a multistage compressor to be compressed before being charged into the cylinders. In the compressor (fig. 87), the pressure is raised to approximately 400 psig. To remove the heat from the gas, there is a forecooler before the first stage of compression, a water-cooled intercooler after each stage of compression (except the last), and a water-cooled aftercooler on the last stage. Water is also condensed out of the gas in the intercoolers and removed through condensate traps. The gas is then passed through a calcium chloride dryer to remove any further traces of water. The gas then flows through a back-pressure regulator valve to another set of flash-back arrester. The purpose of the back-pressure regulator is to prevent any of the low-pressure acetylene from reaching the flash-back arresters or the cylinder charging manifold until the gas pressure reaches approximately 200 psig. The flash-back arresters at this point prevents any flame or spark that might originate in the charging manifold from reaching the compressor. The gas then passes through the charging manifold to the acetylene cylinders or storage. The storage of high-pressure acetylene by dissolving the gas in acetone within a porous filler is covered in paragraph 130*b*.

107. Acetylene Compressor

The acetylene compressor (fig. 87) is a three-stage, four-cylinder machine. Two of the cylinders are used for the first stage of compression. This is necessary in order to handle the large volume of gas which is present before any compression has been done. The compressor is driven by a 5-horsepower electric motor



1 Acetylene discharge
2 Oil pressure gage
3 Acetylene inlet
4 Second intercooler condensate trap
5 Third stage cylinder
6 Forecooler condensate trap
7 Second stage cylinder
8 Second intercooler drain
9 Forecooler drain
10 Oil level sight glass
11 Oil drain plug
12 Oil filler plug
13 Lubricating oil pump
14 First intercooler drain
15 After cooler drain
16 First stage cylinders
17 First intercooler condensate trap
18 Aftercooler condensate trap

Figure 87. Acetylene compressor.

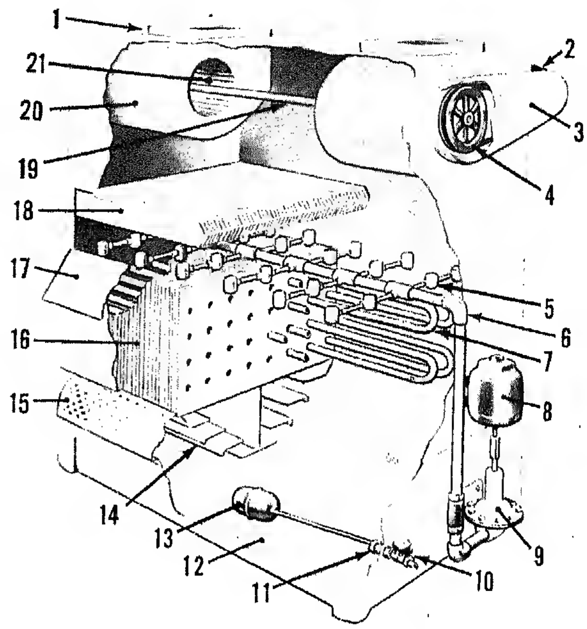
which is enclosed and explosion-proofed to prevent a spark from igniting any acetylene which may be in the trailer. Inlet and outlet valves of the feather or spring type are located in the cylinder heads. On the downstroke the inlet valve opens and the outlet valve closes. As acetylene flows through the compressor assembly, it is compressed and cooled, and the moisture is removed.

108. Water System

Water in the acetylene process serves two purposes. First, it is used to charge the acetylene generator; and second, it is used as a coolant to remove the heat of compression in the forecoolers, intercoolers, and aftercoolers of the compressor. As seen above, water is taken from the source of supply and pumped into the water storage tank. To cool effectively the water in the storage tank should not exceed 24°C. (75°F.). Consequently, the system is usually provided with a water cooler to keep the water below this temperature. The operation of the water cooler is similar to the operation of a spray tower. In this type of cooler (fig. 88) the water is sprayed through nozzles into the air and the accompanying vaporization causes the water temperature to be lowered. When the compressor is running, the cooling water is circulated through the compressor cooling tank to remove the heat of compression. It then returns to the heat exchanger to be recooled. In addition to removing the heat of compression, the cooling water, because of its lower temperature, causes the condensation of some of the remaining moisture in the acetylene. This moisture drains to condensate traps and is periodically removed. This is an important phase of the operation since water is one of the main constituents of the reaction in the formation of acetylene gas. Therefore, the generated gas will contain a large amount of water which must be removed.

109. Air Flow

Compressed air is provided in the trailer to operate the generator control and alarm system. Air rather than electrical control is used because an electric control system could possibly cause an electric spark in the generator and, therefore, defeat the entire purpose of the controls and alarms. Air is compressed to no less



1 Vents
2 Blower motor
3 Belt guard
4 Drive pulley and belt
5 Spray nozzles
6 Inlet to spray header
7 Cooling coils
8 Spray pump motor
9 Spray pump
10 Water shutoff valve
11 Float operated valve
12 Spray collector
13 Float
14 Splash baffles
15 Air inlet grill
16 Cooling coil and fins
17 Access door
18 Spray baffles
19 Blower drive shaft
20 Blower casing
21 Rotary blower

Figure 88. Spray tower.

than 20 psig. filtered to remove any dust, and regulated by a pressure regulator to assure a constant air supply. Air pressure is used to operate the temperature safety control, inlet-water temperature control, and the high- and low-level alarms. These controls, requiring a constant air supply, operate as follows:

a. The water-temperature control regulates an air-operated valve to control the inlet water which controls the temperature of the generator.

b. The temperature safety control operates a pneumatic alarm switch which will sound an alarm when the temperature in the generator exceeds a safe point.

c. The high- and low-level water alarm-device operates a pneumatic alarm switch to sound an alarm should the water in the generator fall below or exceed the correct level. Actually the only time the high- and low-level controls should actuate the pneumatic alarm is

when the drain valve becomes clogged or is not functioning. In this case, the alarm switch would sound and corrective action would be taken immediately.

110. Acetone System

The acetone system is simple. Acetone is pumped from a tank to a two-way valve. The valve directs the flow of acetone either to the scales where it is used to refill the acetylene tanks or back to storage. Due to the flammable nature of acetone, the pump is of explosion-proof and fireproof construction. A detailed description of the procedure to be used in handling and replenishing the acetone in acetylene cylinders is covered in paragraphs 123 and 124.

111. Fuel System

a. Diesel Fuel. Diesel fuel is stored in the fuel storage tank in the engine compartment of the trailer. From the storage tank, the fuel flows through the fuel oil line to the fuel injector pump. Any excess oil is returned to the tank by a similar line. The tank is filled either by a motor driven pump or by a hand pump. The hand pump is used when it is not possible to use the motor driven pump.

b. Gasoline. The personnel heater uses gasoline as a fuel. It is stored in the gasoline compartment of the fuel storage tank. From the storage tank there are two gasoline lines, one to each personnel heater fuel pump. The gasoline is pumped into the storage tank by a hand operated pump. This gasoline flows through the suction line to the pump. From there it flows to the storage tank.

112. Summary

The generation of acetylene is a relatively simple process, but caution must be used because of the possibilities of explosion. The disposal of the calcium hydroxide (commonly known as lime slurry) should be taken into consideration when selecting a site for the mobile unit.

Section IV. DESCRIPTION OF TYPICAL ACETYLENE GENERATOR

113. Acetylene Generator

Because the acetylene generator is unique to the carbide process, and because it was not covered in detail in previous sections, it is described more fully in this section to give a clear understanding of the carbide process. All acetylene generators, irrespective of manufacturer, are similar in construction. The generator consists of the generator tank proper with its accessory equipment, the carbide hopper and feed mechanism, and the flash-back arrester.

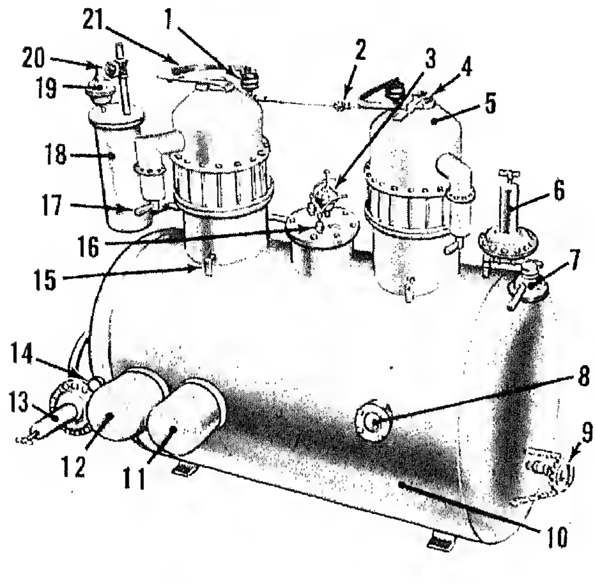
114. Generator Tank

The acetylene generator (fig. 89) is a cylindrical tank having two identical carbide hoppers mounted on its top. The feed water-inlet valve and the flash-back arresters are also mounted on the top of the generator, on the right and left side, respectively. The water-level alarm control, the residue drain-valve control, and the residue drain valve are located near the bottom of the tank. Two gas-filled bulbs are mounted in the generator and expand or contract in accordance with temperature in the generator, actuating the temperature control and the temperature high-limit control.

115. Carbide Hopper and Feed Mechanism

A cross section of the carbide hopper mechanism is shown in figure 90. Initially, the operating lever is placed in the feed position, which allows the carbide to enter the generating tank. When the pressure in the generator has reached a predetermined pressure setting (approximately 10 psig), the pressure regulating mechanism operates the feed valve and automatically controls the pressure in the generator. The control positions of the operating lever are shown in figure 91. Automatic control of the carbide hoppers is maintained as follows:

a. Primary Hopper. The pressure in the generator exerts a force on a diaphragm bellows mechanism. An increase in generator pressure raises the diaphragm which is mechanically linked through a stem to the feed valve. As the diaphragm bellows moves upward under increased pressure, the feed valve partially closes, checking the flow of carbide, which reduces the



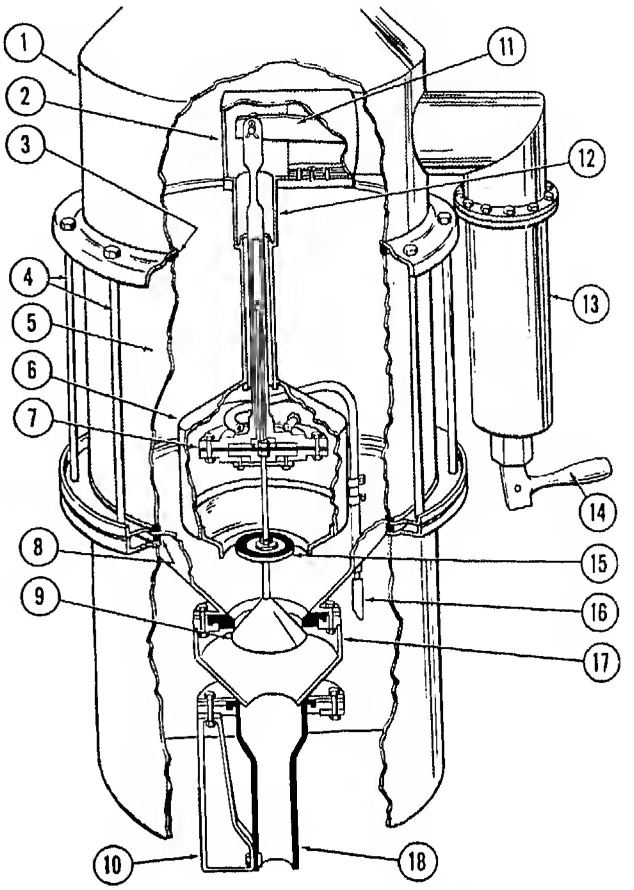
1 Hopper vent valve
2 Hopper equalizer valve
3 Water-shell pressure-relief valve
4 Carbide fill cap
5 Carbide hopper
6 Water-inlet valve
7 Water meter
8 Water-level sight glass
9 Agitator-shaft sprocket
10 Water shell
11 Water-level alarm control
12 Residue drain-valve control
13 Residue drain valve
14 Residue drain-valve air-pressure gage
15 Throat cleaner
16 Temperature bulbs
17 Operating lever
18 Flashback arrester
19 Flashback arrester pressure relief valve
20 Acetylene discharge valve
21 Vent valve lever

Figure 89. Acetylene generator.

generator pressure automatically. Conversely, when the pressure falls below the minimum setting, the diaphragm will move downward, allowing more carbide to enter the generator, returning the pressure to the predetermined setting.

b. Secondary Hopper. The secondary hopper maintains a constant pressure in the generator during replenishment of the carbide supply in the primary feed. The secondary hopper feed is actuated at a pressure slightly lower than that of the primary hopper. Consequently, when the pressure in the primary hopper drops to the pressure setting of the second hopper, the feed valve in the second hopper is automatically opened and the generator receives the carbide directly from it. This keeps the generation process in operation.

c. Pressure Settings. Hopper-pressure set-



1 Hopper top
2 Inner cover
3 Glass cylinder gasket
4 Bolts
5 Glass cylinder
6 Pulsator cover
7 Pulsator assembly
8 Hopper to tank gasket
9 Feed valve
10 Throat-cleaner bumper
11 Feed lever
12 Pulsator-cover guide
13 Pressure-regulating mechanism
14 Operating lever
15 Upper shutoff valve
16 Pulsator hose
17 Hopper skirt
18 Carbide feed throat

Figure 90. Carbide hopper.

tings are changed or varied in relation to the desired output of the plant (table XII, app. II). As the pressure is increased the amount of acetylene produced is increased. The temperature of the reaction is controlled by the water inlet temperature (in hot weather a cylinder spray system is provided for cooling the acetylene cylinders during charging) and consequently is not a variable in the plant's production of acetylene.

116. Flash-Arrester Filter

In the flash-back arrester shown in figure 92 the acetylene gas enters the bottom of the

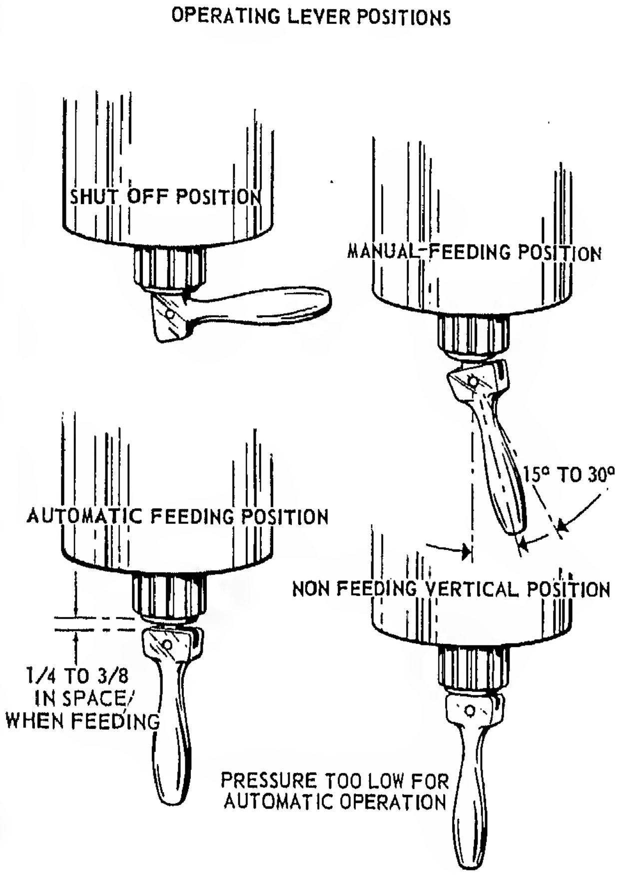
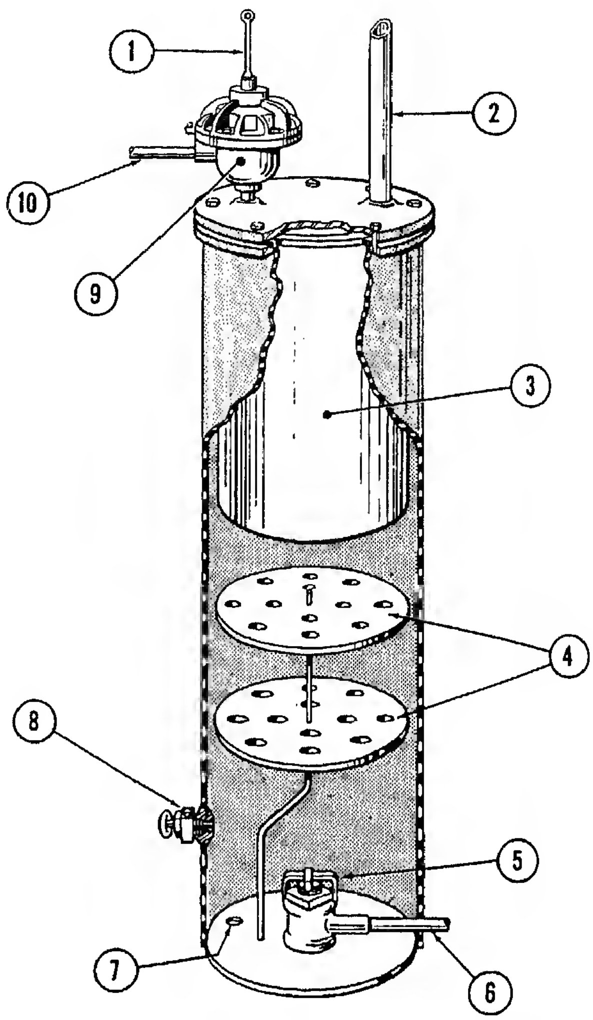


Figure 91. Operating lever positions.

arrester through the inlet and is bubbled through the water in the arrester. The water is supplied through the water-filling valve. The baffle plates in the arrester and the filter cartridge directly above the baffle plates help to remove some of the water entrained with the gas before the gas passes to the compressors.



1 Pressure-relief-valve lever
2 Acetylene discharge line
3 Filter cartridge
4 Baffle plate
5 Check valve
6 Flash-arrester inlet
7 Drain plug
8 Water-filling valve
9 Pressure-relief valve
10 Pressure-relief-valve vent

Figure 92. Flash back arrester

Note. For more detailed information on the foregoing equipment, reference should be made to the manufacturer's equipment manual.

Section V. PLANT LAYOUT

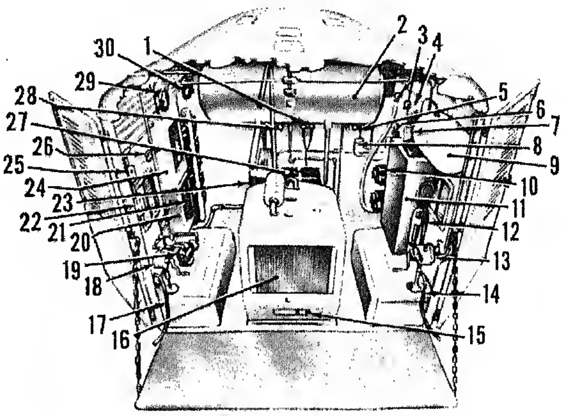
117. Internal Plant Layout

Before attempting to operate the unit, all personnel should acquaint themselves with the location of the equipment used in the generation process. All the necessary equipment for producing and compressing acetylene is installed in a van-type semitrailer which is divided into two compartments by a partition wall. The electric generator set is installed in the rear compartment which is provided with ventilators in the roof and sidewalls and ventilating louvers in the rear doors (fig. 93). The tailgate provides

additional working space. The larger forward compartment contains all the equipment for the production and compression of acetylene. Entrance doors with demountable steps are provided on both sides of the trailer body. The van-type trailer (fig. 94) measures 29½ feet long, 8 feet wide, and 11 feet high, and weighs 15 tons in operation. The trailer body is of steel, with insulated walls and roof, and a wood floor. Four manifold doors, on both sides of the trailer, provide a means for connecting cylinders to the charging manifold. The trailer has dual rear wheels on a single axle. The front of the trailer may be supported by landing gear. A towing dolly comes with the acetylene generator. Using this dolly, a 5-ton truck can move the plant. If the dolly is not available, an M–52 tractor can tow the plant.

118. External Plant Layout

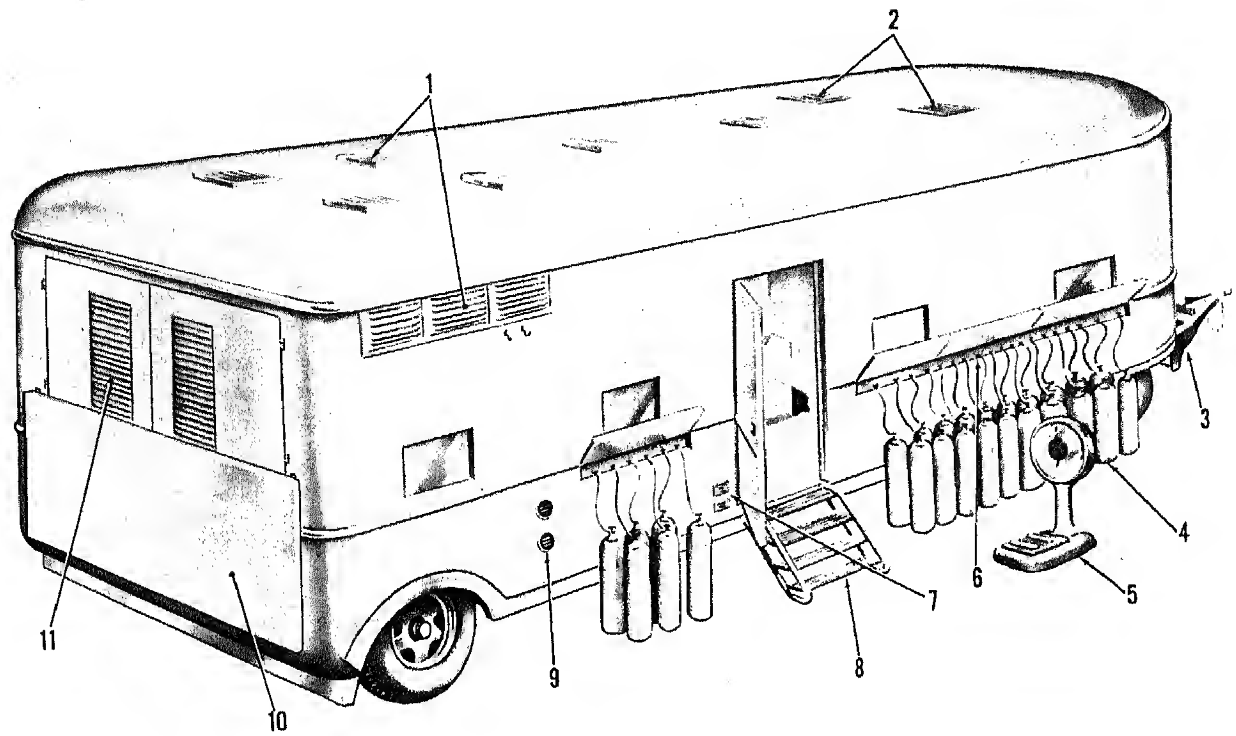
In choosing a site for the acetylene-generating plant, the factors to be considered include available water source, uncontaminated atmosphere, surrounding conditions, and proper trailer installations. These factors are the same as those discussed in detail in chapter 2 and shown in figure 54. In addition, due to the nature of acetylene, special consideration should be given the surrounding atmosphere to avoid contamination which could lead to explosion. Special



1 Fuel oil shutoff valves	16 Electric generator set
2 Fuel storage tank	17 Fuel oil suction hose
3 Heater exhaust	18 Fuel oil hand pump
4 Control switch, air compressor	19 Fuel oil power pump
5 Gasoline gage	20 Selector switch
6 Heater fuel pump	21 Motor starters
7 Air compressor	22 Light switches
8 Gasoline shutoff valves	23 Control panel, electric generator
9 Air receiver tank	24 Multibreaker panel
10 Heaters	25 Pushbutton switch, fuel oil pump
11 Tool cabinet	26 110-volt receptacle
12 Carbon dioxide fire extinguisher	27 Storage batteries
13 Gasoline hand pump	28 Fuel oil gage
14 Gasoline suction hose	29 Pressure switch inclosure
15 Carbon tetrachloride fire extinguisher	30 Flame arrester

Figure 93. Rear view of engine-compartment equipment.

consideration should also be given to a means of disposing of the large amount of calcium hydroxide formed as a byproduct in the generation process.



1 Engine-compartment ventilators	3 Towing dolly	7 Nameplate and date plate	10 Tailgate
2 Heat-exchanger vents	4 Acetylene cylinders	8 Steps	11 Rear-door ventilating louvers
	5 Dial scales	9 Air-intake louvers	
	6 Charging manifold		

Figure 94. Trailer, right-rear view.

Section VI. SAFETY AND PREVENTIVE MEASURES

119. Introduction

This section will cover the specific safety precautions required in the generation of acetylene. Because of the dangerous nature of the material, these precautions are emphasized again and again in this manual. All personnel associated with gas generating should be held strictly accountable for knowing the hazards and observing the safety rules given below. All others working with or handling acetylene should also know these safety precautions.

120. Acetylene

a. Hazards. Acetylene is stable and safe to handle as charged in standard Army acetylene cylinders. However, in the free gaseous state, or if compressed in cylinders not designed for acetylene, it is very unstable and likely to decompose violently. In large volumes, at pressures exceeding 15 psig, acetylene is dangerously explosive. This means that acetylene can explode of its own accord when improperly stored or handled. It does not always need air or oxygen or a spark to help it explode. Any shock or heat may be enough to set acetylene off if it is stored at a pressure higher than 15 psig. When mixed with air or oxygen, the chances of violent explosion are increased. Acetylene in copper piping systems or in piping systems with silver-brazed joints may form a compound by the replacement of hydrogen in the acetylene with silver or copper (C_2Ag_2 or C_2Cu_2 rather than C_2H_2). These compounds, called acetylides, are violently explosive and can be detonated by shock or heat.

b. Safety Rules for Acetylene.

(1) Acetylene is inherently unstable and at pressures greater than 15 psig may

dissociate violently when subjected to heat or shock. Since the pressure within the acetylene cylinders is approximately 400 psig, use extreme care at all times when handling these cylinders.

(2) Use acetylene cylinders only in the correct position, with the valve end up to avoid the possibility of withdrawing the acetone when the cylinders are being discharged. They may be stored in any position, but must be placed upright at lease 2 hours before being used.

(3) Never transfer acetylene from one cylinder to another, and do not mix any other gas with it in the cylinder. It is possible to charge or refill acetylene cylinders safely only with special equipment (ch. 5).

(4) Keep sparks and flames away from acetylene cylinders. Do not under any circumstances allow a flame to come in contact with the safety devices.

(5) Never allow acetylene cylinders to come in contact with electrical welding apparatus or circuits.

(6) When it is necessary to test for leaks, use soapy water.

(7) Do not interchange acetylene regulators, hose, or other appliances with similar equipment intended for other gases.

(8) Use only approved manifolds.

(9) Never use homemade or improvised acetylene generators.

(10) Always keep the wrench or hand wheel used for opening the cylinder valve on the valve spindle when the cylinder is in use.

(11) Do not use the recessed top of the cylinder as a place for tools.

(12) Keep in mind that the amount of acetylene in a cylinder is determined by weight, and the pressure in a cylinder does not accurately indicate the amount of gas contained therein.

121. Calcium Carbide

a. Store carbide in a place that is dry, waterproof, and well ventilated.

b. Do not allow carbide to come in contact with water or moisture outside the generator. Water or moisture in the air will for acetylene with calcium carbide and create acetylene outside the generator. Therefore, always replace and securely fasten the covers on partially full or empty carbide containers. Make sure that the screw cover is closed with the gasket in place. Empty containers should be completely clean of carbide before closing. If carbide or carbide dust is spilled on the floor of the generator room, it should be swept up immediately and thrown in the pit used for the carbide residue.

c. Use carbon dioxide extinguishers rather than water on fires involving carbide.

d. Do not place lights of any kind, or any other possible source of ignition, into or near a carbide container.

e. Handle carbide and carbide drums with reasonable care. When removing carbide from drums to charge the hopper, do not use scoops or shovels which might cause sparks. Monel metal or wood tools are suitable. Handle carbide drums so they will not be damaged.

f. Discharge the carbide residue into a pit which should be located at least 30 feet from the plant. Since the carbide residue is slaked lime, some of it can be used for whitewash.

122. Fire Fighting

See paragraph 52.

Section VII. FILLING CYLINDERS

123. Introduction

Upon completion of the inspection, servicing, and repair of an acetylene cylinder, which will be discussed in detail in chapter 5, the cylinder is ready to be filled. The next paragraph describes the procedure to be followed in filling acetylene cyliders.

124. Filling Procedure

a. Determine acetylene capacity by referring to table XIII in appendix II.

b. Check the cylinder with a residual gas-pressure gage. (See paragraph 139*c* for details.)

c. Weigh the cylinder (fig. 95).

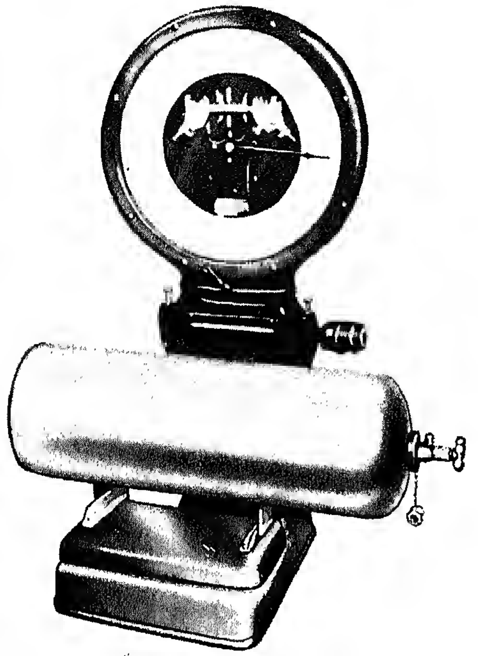


Figure 95. Weighing an acetylene cylinder.

(1) If the cylinder has no pressure but weighs more than the stamped weight, it probably contains excess acetone, oil, or water. Assume the cylinder containes excess acetone and proceed to remove the excess as follows:

(*a*) Place the cylinder on the charging rack and charge the cylinder with 100 psig of acetylene. Do not charge acetylene faster than 1 cubic foot per minute per cylinder.

(*b*) Allow the acetylene to dissolve in the cylinder for 3 hours.

(*c*) Remove the cylinder out-of-doors at least 100 feet away from the plant in a downwind direction and lay it on its side. Open valve slowly and allow the contents to escape until there is no longer any pressure in the cylinder. All sources of ignition must be eliminated in the area during this operation.

(*d*) Reweigh the cylinder.

(*e*) If the weight is not down to stencil weight, repeat the process.

(*f*) If the weight does not come down after three attempts, discard the cylinder.

(2) If the pressure is under 10 psig and the cylinder is underweight, add acetone until the stamped weight is reached.

(3) If the pressure is over 10 psig, the cylinder still should be weighed as a precautionary measure to determine if acetone is needed or should be removed.

d. Connect the cylinder to the charging manifold and charge the cylinder to capacity. Remember not to charge acetylene faster than 1 cubic foot per minute per cylinder. To prevent this, the output of the compressor must be known.

e. Soap leads and valves to test for leaks. Tighten leads if leaks are found. Soap test fusible plugs also.

f. After 2 hours of compressor time or if the manifold pressure is 250 psig or more, weigh the cylinders to determine the amount of acetylene charged. Keep checking the weight until the cylinders are full or 400 psig of pressure has been reached.

g. At this stage stop the compressor, remove the cylinders, and record the weight.

CHAPTER 5

COMPRESSED GAS CYLINDERS

Section I. INTRODUCTION

125. Problem of Storage

Gaseous products because of their physical properties present a problem in storage. A partial solution to large-volume storage of a particular gas (CO_2) was covered previously in paragraphs 80 through 82. From this discussion as well as the basic theory discussed in previous chapters, it can readily be seen that it would be both unfeasible and uneconomical to store gases at atmospheric pressure since the space required to hold a reasonable amount would be too large. Consequently, it is necessary to compress the gases to a high pressure in order to contain useful volumes in a reasonable space. This has been done through the wide application of cylinders for the storage of all types of gases. The following information has been included, therefore, for the purpose of instructing personnel in the safe handling, storing, shipping, and using of cylinders containing compressed gases.

126. Definitions

a. Compressed Gas. A compressed gas is one which is confined under a pressure greater than atmospheric pressure. The Interstate Commerce Commission in its shipping regulations defines a compressed gas as "Any material with a gage pressure exceeding 25 psi at 21°C. (70°F.), or any flammable liquid having a vapor pressure exceeding 40 psia at 38°C. (100°F.), March to October inclusive or exceeding 45 psia, November to February, inclusive."

b. Liquefied Gas. A liquefied gas becomes liquid at the pressure and temperature at which it is normally charged into cylinders for shipment and use. Such liquefied gases return to the gaseous state when the pressure is released.

c. Combustion. Combustion is defined as any chemical process accompanied by the giving off of light and heat. Combustible gases are those which burn or explode when united with another material.

127. Classification of Gases

a. The compressed gases used in industry and by the Army which are discussed in this manual can be grouped into four broad headings, as follows:

(1) *Flammable nonliquefied gases*—hydrogen.

(2) *Flammable liquefied gases.*
- (*a*) Acetylene (dissolved).
- (*b*) Methyl chloride.
- (*c*) Ammonia (when heated above 650°C. (1,200°F.).
- (*d*) Propane.
- (*e*) Butane.
- (*f*) Miscellaneous other petroleum gases.

(3) *Nonflammable nonliquefied gases.*
- (*a*) Oxygen.
- (*b*) Nitrogen.
- (*c*) Helium.
- (*d*) Argon.
- (*e*) Nitrous oxide.

(4) *Nonflammable liquefied gases.*
- (*a*) Carbon dioxide.
- (*b*) Freon.
- (*c*) Chlorine.
- (*d*) Sulphur dioxide.

b. Flammable gases are also sometimes termed "red label" gases because the Interstate Commerce Commission regulations require any cylinder containing such a gas to bear a red label. Nonflammable gases are similarly termed

"green label" because of a similar requirement. Some of these gases are also toxic or corrosive and require special precautions in shipping, handling, and use.

128. Hazards of Gases

a. General. Most compressed gases are under high pressure and must be handled cautiously. Those that are flammable and explosive must be handled with particular care. Compressed gas cylinders must never be allowed to come in contact with fire, sparks, or electrical circuits since this could cause an explosion. Because compressed gas cylinders are made of steel, these explosions have the same destructive effect as a bomb explosion.

b. Anesthetic Gases. Anesthetic gases exert a druglike action when breathed because they are absorbed into the blood. They may cause death when breathed in considerable quantities.

c. Irritant Gases. Irritant gases are not absorbed into the blood but injure the surface tissue of the breathing passages. Death may result from continuous exposure due to the contraction of the respiratory tract.

d. Toxic Gases. Toxic gases are poisonous since they exert a chemical action on the body tissue and prevent it from absorbing oxygen from the blood.

e. Harmless Gases. Harmless gases are harmless when breathed in small quantities, but death may result from suffocation when inhaled in large quantities because they prevent oxygen from reaching the lungs. A summary of the hazardous effects of gases along with other pertinent characteristics is shown in table VIII.

Table VIII. Characteristics of Gasses

Gas	Color	Odor	Weight when compared to air	Physical state as shipped	Physical effect
Acetylene	None	Garliclike	Lighter	Dissolved	Anesthetic
Ammonia	None	Pungent	Lighter	Liquid	Irritant
Butane	None	Sewer gas	Much heavier	Liquid	Anesthetic
Carbon dioxide	None	Faint	Much heavier	Liquid	None*
Chlorine	Greenish yellow	Disagreeable	Much heavier	Liquid	Irritant
Helium	None	None	Much lighter	Gas	None*
Hydrogen	None	None	Much lighter	Gas or liquid	None*
Hydrogen cyanide	None	Peach blossom	Lighter	Liquid	Toxic
Methyl chloride	None	Etherlike	Heavier	Liquid	Anesthetic
Nitrogen	None	None	Slightly lighter	Gas or liquid	None*
Oxygen	None	None	Slightly heavier	Gas or liquid	None*
Propane	None	Sewer gas	Heavier	Liquid	Anesthetic
Sulfur dioxide	None	Disagreeable	Much heavier	Liquid	Irritant
Nitrous oxide	None	Sweet	Much heavier	Gas or liquid	Anesthetic

* Excessive amounts cause suffocation

Section II. CYLINDERS

129. Introduction

With the exception of cylinders designed specifically for the storage of acetylene, high-pressure compressed gas cylinders are all similar in construction, and are manufactured mostly of steel under various Interstate Commerce Commission specifications. These are described in detail in AR 700–8120–1.

130. Construction

a. High-Pressure Cylinders. Since oxygen is one of the most common and widely used industrial gases, the cylinders used to store it will be taken as an example. Although aluminum cylinders are coming into use, most oxygen cylinders (fig. 96) are constructed of seamless drawn steel, or they are spun from seamless steel tubes and are available in plain carbons, alloys, or stainless steels. They are usually made by pushing a heated steel plate through a cylindrical hollow mandrel with a plunger. This is done in several operations until the vessel has the shape of an open-ended deep vessel of the approximate diameter of the finished

cylinder. The cylinder is again heated and the open end swaged or spun down to a small bottle-shaped neck. The cylinder is finally heat treated to relieve the stresses introduced by shaping the steel, tested, and the neck is threaded internally for the cylinder valve. All threads in cylinders of this type are right hand. Valve outlet threads, however, are either right or left hand. As a safety measure to insure that oxygen does not come in contact with oil or hydrogen, a neck ring having a thread for the cylinder cap is peened in the neck. Oxygen cylinders are made in several sizes but the size most frequently used contains 240 to 250 cubic feet of oxygen and is approximately 9 inches in diameter and 51 inches high, or 56 inches including the valve protection cap. It is normally charged to a pressure of 2,265 psi at 21° C. (70° F.). The average empty weight of a 240 to 250 cubic-foot alloy steel cylinder is 112 pounds, whereas a carbon steel cylinder weighs 125 pounds. All cylinders are carefully tested at a pressure above the maximum pressure to which it is permissible to charge them.

b. Low-Pressure Cylinders.

(1) An acetylene cylinder is a good example of a low-pressure storage vessel. Compressed acetylene may be stored in cylinders of varying capacity. It is rated as weighing 1 pound per 14½ cubic feet under atmospheric pressure and normal temperatures. The most common storage cylinder for acetylene (fig. 97) measures about 36 inches high and 12 inches in diameter. This type of cylinder weighs about 180 pounds when filled with 225 cubic feet of acetylene and 165 pounds empty. It is made of steel. Since it has to withstand a much lower pressure than the oxygen cylinder (250 psig versus 2,265 psig) it does not have to be of seamless construction, and the majority have a welded seam around the middle. All cylinders of this type are also equipped with fusible safety plugs at the top and bottom to relieve excessive internal pressure as a result of fires or high temperatures. Normally, a fuse plug of steel having a ⅛-inch standard pipe thread and a hexagon head is used. The inside channel of the plug is filled with a fusible metal which melts at a temperature of 60° to 75° C. (140° to 165° F.), depending upon the metal alloy used.

(2) Since free acetylene must never be stored above 15 psig, the acetylene cylinders are packed with an approved substance having a porosity in excess of 83 percent. Originally, acetylene cylinders were filled with a porous material saturated with cement, but this resulted in a very heavy cylinder which was hard to handle. Later development led to a filler composed of

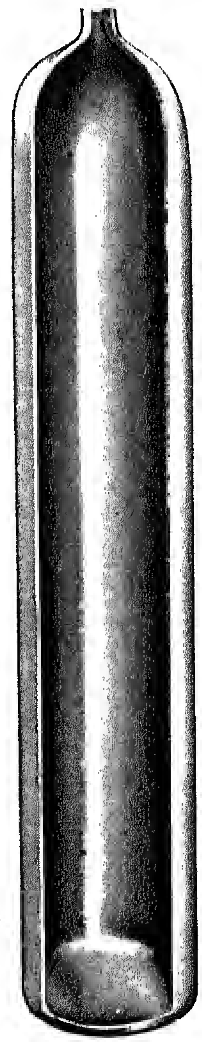


Figure 96. Oxygen cylinder.

such materials as asbestos, infusorial earth, silk fiber, charcoal, and other substances. This porous material packed in the cylinder is in turn saturated with acetone. The porous material so saturated has the capacity of absorbing up to 25 times its volume of acetylene at normal atmospheric pressure and temperature. Raising the pressure or lowering the temperature in a cylinder under normal or abnormal conditions raises the absorptive capacity of the acetone in direct proportion. Under 2 atmospheres of pressure acetone will absorb up to 50 times its volume of acetylene.

(3) The normal weight of the cylinder is always stencilled on the shoulder, and indicates the weight of the cylinder when filled with the correct amount of acetone. If the cylinder weighs less thant the stencilled weight, it must be filled with acetone to bring it up to weight before it is charged.

131. Cylinder Identification

a. Domestic.

(1) The compressed gas cylinders used in the United States have two types of identifying designations. One of those is stamped into the metal of the cylinder at the shoulder top or neck, or with a neck ring as close to the neck as possible, in a downward sequence as shown in figure 98. The other is a color code identifying the different types of gases the cylinders contain.

(2) The stamped markings which should normally appear on cylinders are described in detail in AR 700–8120–1 which covers the safe handling, storing, shipping, using, and disposal of compressed gas cylinders.

(3) The Department of the Army has adopted a standard color code in accordance with Mil Std 101–A. The use of this standard reduces the chances for error and confusion as to the type of gas contained in a given cylinder. It is considered an auxiliary means of identifying cylinder contents by personnel engaged in handling, storing, and shipping gas cylinders. Trained personnel, however, should also rely on the form, type, and size of valve-outlet threads, markings on cylinder valve, and stencilling on the cylinder as a positive means of cylinder content identification. The colors of the main portion of cylinder bodies are selected to group the materials according to general characteristics. To aid in distinguishing between materials in the same general group color, bands are used. For example, acetylene and hydrogen cylinders both belong to the flammable material group. Cylinders in this group are painted yellow. To differentiate between the acetylene and hydrogen cylinder (fig. 99) a black band, approximately 2 or 3 inches wide, is

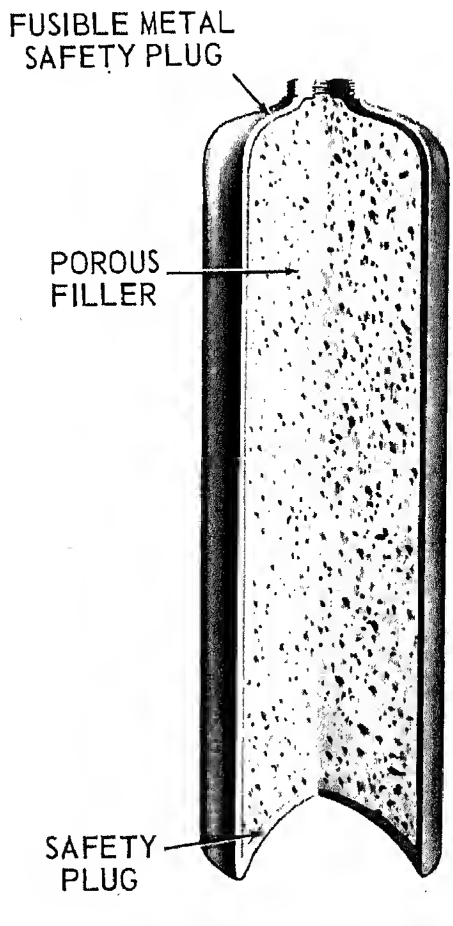


Figure 97. Acetylene cylinder.

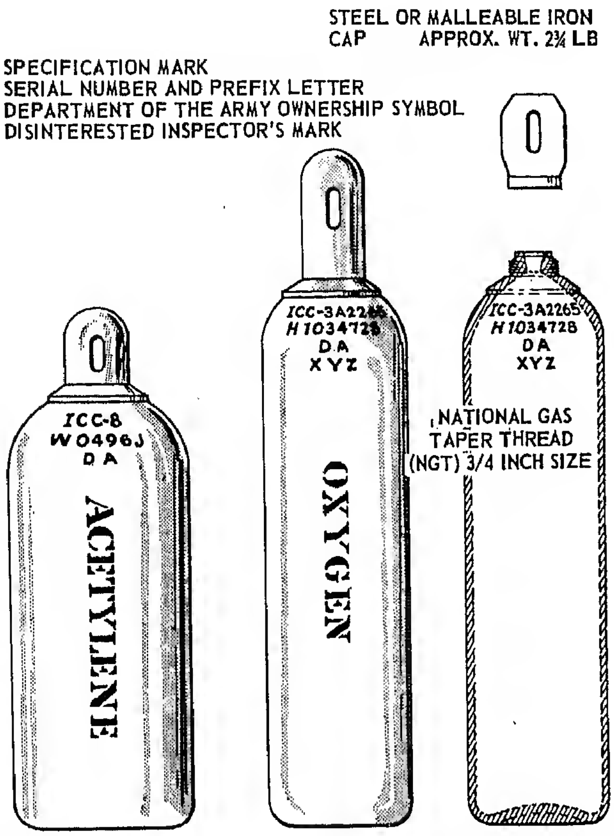


Figure 98. Permanent stamped markings on cylinders.

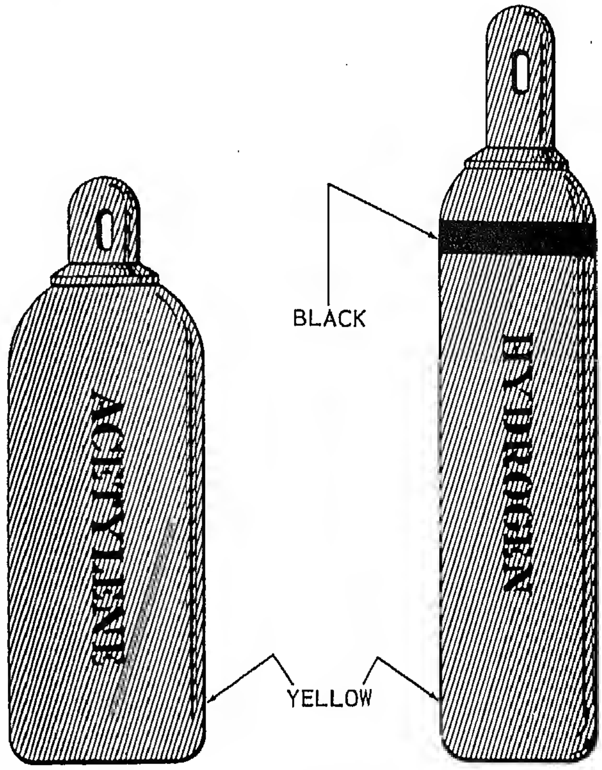


Figure 99. Differentiation between acetylene and hydrogen cylinder markings.

painted around the hydrogen cylinder at a point near the top of the cylinder.

b. General Color Classification. The colors for the six general classifications are—

(1) Yellow—Flammable materials.
(2) Brown—Toxic and poisonous materials.
(3) Blue—Anesthetics and harmful materials.
(4) Green—Oxidizing materials.
(5) Gray—Physically dangerous materials.
(6) Red—Fire protection materials.

c. Common Gas Cylinder Color Markings. The more common cylinders in the gas generating field are—

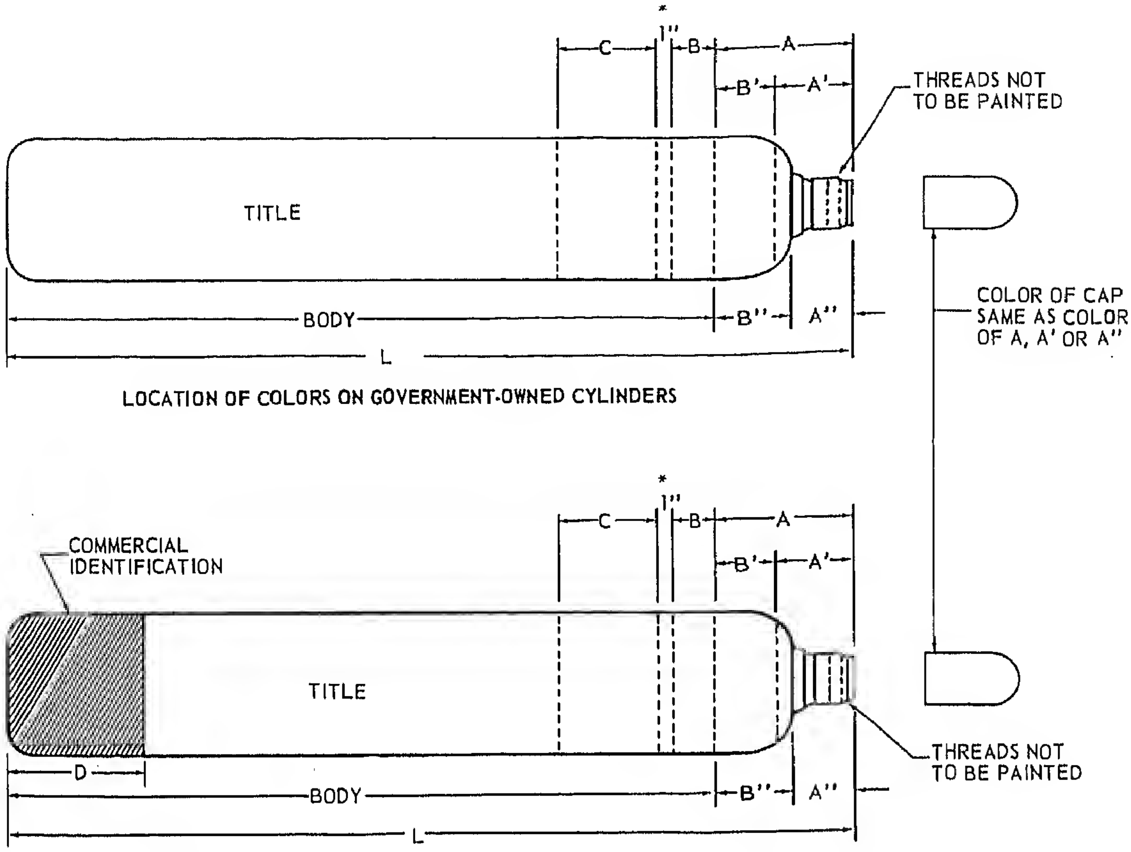
(1) Oxygen—Green.
(2) Acetylene—Yellow.
(3) Carbon dioxide—Gray.
(4) Hydrogen—Yellow with a black band.

d. Markings for Other Materials. Other materials are stored in cylinders colored as follows:

(1) Nitrogen—Gray with one black band (oil pumped). Gray with two black bands (water pumped).
(2) Helium—Gray with one orange band (oil pumped). Gray with a buff top (oil free).
(3) Freon—Orange.
(4) Ammonia—Orange with brown top and one yellow band.
(5) Methyl chloride—Orange with yellow top and one brown band.
(6) Nitrous oxide—Blue.

e. Special Gas Cylinder Color Markings. The special gas-cylinder color markings prescribed in Mil Std 101–A as well as the common gas-cylinder color markings described above are listed in table XV in appendix II, and are located on the cylinder as shown in figures 100 and 101.

f. Labels. Combination diamond shaped labels printed on one side as a caution label and on the other as a shipping tag (fig. 102) conforming to Interstate Commerce Commission (I.C.C.) specifications are attached to cylinders,



LOCATION OF COLORS ON GOVERNMENT-OWNED CYLINDERS

LOCATION OF COLORS ON COMMERCIAL-OWNED CYLINDERS

LOCATION DIMENSIONS

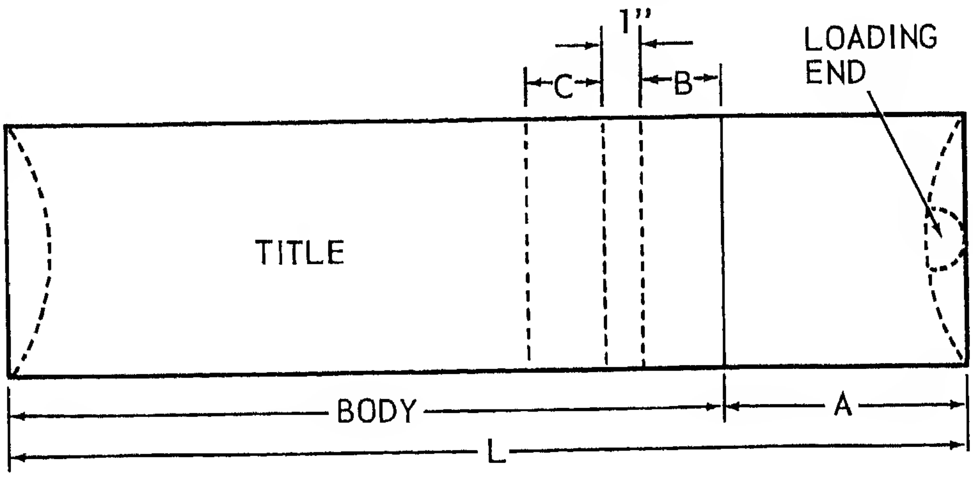
ON CYLINDERS FOR MEDICAL GAS MIXTURES, 1" SPACE AND BAND C ARE LOCATED IMMEDIATELY BELOW BANDS B' OR B"

CYLINDERS FOR	OVERALL LENGTH L	SHOULDER COLOR(S)			CYLINDER COLOR BAND(S)				COMMERCIAL IDENTIFICATION
		A	A'	A"	B	B'	B"	C	D
MEDICAL GAS MIXTURES	OVER 30"	L/5	3½"	--	--	A LESS 3½"	--	3"	L/6
OTHER GASES	"	L/5	--	--	3"	--	--	3"	L/6
MEDICAL GAS MIXTURES	30" AND UNDER	L/5	--		--	--	A LESS A"	2"	L/6
OTHER GASES	"	L/5	--	--	2"	--	--	2"	L/6

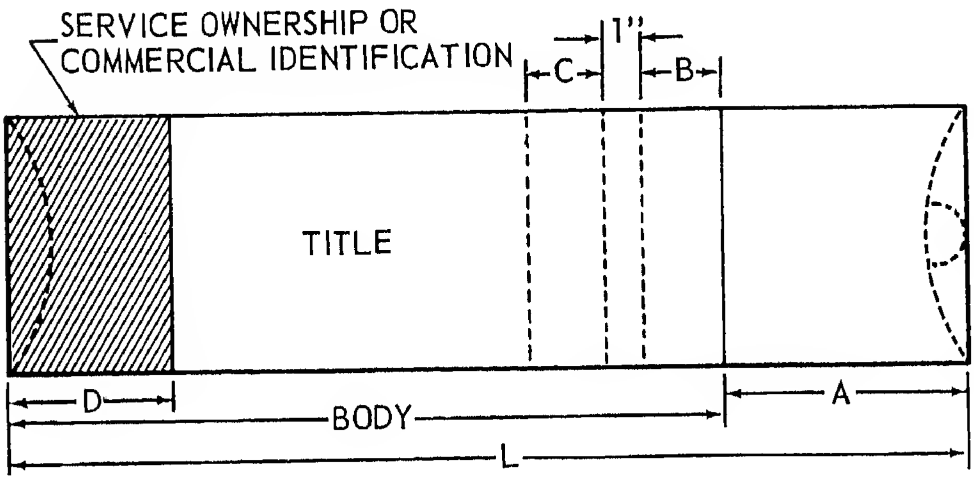
FROM CYLINDER TOP TO BOTTOM OF NECK RING

*1" SPACE TO BE OMITTED IF BANDS B & C ARE OF DIFFERENT COLORS

Figure 100. Location of colors on bottle type cylinders.



LOCATION OF COLORS ON GOVERNMENT – OWNED CYLINDERS



LOCATION OF COLORS ON COMMERCIAL – OWNED CYLINDERS

LOCATION DIMENSIONS

OVERALL LENGTH	CAP AND SHOULDER COLOR	CYLINDER COLOR BAND(S)	COMMERCIAL IDENTIFICATION
L	A	B & C	D
OVER 30"	1/4 OF L	3"	1/6 OF L
30" AND UNDER	1/4 OF L	2"	1/6 OF L

Figure 101. Location of colors on tube type cylinders.

and further serve to identify their content. The red label tag indicates a flammable gas, and the green label tag indicates a nonflammable gas. Label tags should not be removed until the cylinders are empty. The side of the label tag used as a shipping tag has colored corners or borders to show the type of shipping service required. This eliminates the previous practice of marking the cylinder or cap with a paint dot.

g. Foreign Markings. Due to the language and systems of color codes, care should be taken in charging, filling, handling, or emptying partially filled foreign cylinders. As an aid in determining the type of gas being handled, and in addition to the stamped lettering which may appear on the cylinder, the common foreign color markings for the major gases are listed in table IX.

Table IX. Foreign Cylinder Colors

Gas	England	Australia	Japan	Italy	Germany	United States
Aceytlene	Purple	Maroon	Brown	Orange	Yellow	(See detailed table XV in appendix II.)
Carbon Dioxide	Black	Brown	--------	Yellow	--------	
Freon 12	--------	Light green	--------	--------	--------	
Helium	Brown	Gray	--------	--------	--------	
Hydrogen	Red	Signal red	Red	Red	Red	
Methyl Chloride	--------	Light green	--------	--------	--------	
Nitrogen	Gray	Dark gray	Purple	Green	Green	
Oxygen	Black	Black	Black	White	Blue	

Figure 102. Combination identification and shipping tag.

132. Tests

Cylinders, except as otherwise provided for by applicable I.C.C. regulations, must be subjected to an interior hydrostatic test at least once every 5 years. Ordinarily arrangements are made to have this test performed by commercial firms. A cylinder that has been in a fire must not be put in service again until it has been heat-treated and retested. Acetylene cylinders need not be heat-treated but only tested to determine whether the porous filler is u: changed and intact.

133. Shipping

Detailed information on shipping regulatioı is given in AR 700–8120–1.

134. Disposition

The approved method for disposing of su plus and unserviceable cylinders is covered : AR 700–8120–1.

Section III. CYLINDER VALVES

135. Valve Construction

A valve is used to confine a gas under pressure within a cylinder, or to release it under a controlled flow. Cylinder valves are usually made of forged brass, bronze, or steel, and come in a variety of sizes. They are designed so that, when opened either with hand-operated wheels or wrench-operated spindles, the gas will flow into the valve body past the outlet connection and into the pressure regulator. Figures 103, 104, 105 and 106 show typical outside, cutaway and cross sectional views of different types of valves used on cylinders. As can be seen by the figures, a rubber, asbestos, leather, or metal diaphragm or packing prevents leakage of the gas above the valve stem when the valve is opened.

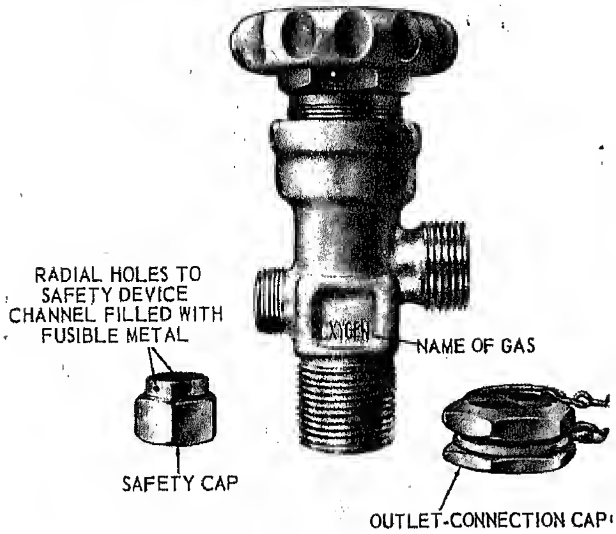


Figure 103. Oxygen cylinder valve.

136. Valve Safety Devices

a. General. The majority of the valv shown, except that in figure 106, have safe caps or devices which act as a pressure reli system to prevent the cylinder from explodiı when exposed to conditions which create und pressure within the cylinder. In general, cylinder safety devices may be divided into fo categories, as follows:

b. Fusible Plugs. Fusible plugs are used safety devices on some valves and cylindeı Fusible plugs are required for cylindeı equipped with valves which have no safety d vice.

c. Spring-Loaded Safety Device. Sprin loaded safety devices usually function as p valves when the internal pressure in a cylind overcomes the spring tension, permitting gas escape. Devices of this sort are used on liqu fied petroleum gas valves.

d. Safety Device with Unbacked Ruptu Disk. Safety device with unbacked safety di consists of a cap containing a rupture disk r backed by fusible metal. The safety device co ers the safety part in the valve. Under exc sive pressures ranging from 2,700 to 3,000 p the safety disk ruptures and allows the gas the cylinder to vent to the atmosphere. Tl type of safety device is used in carbon dioxi service.

e. Safety Device with Backed Rupture Di Safety device with backed rupture disk is t same as the safety device with unbacked ru ture disk except that the disk is supported fusible metal contained in the safety cap

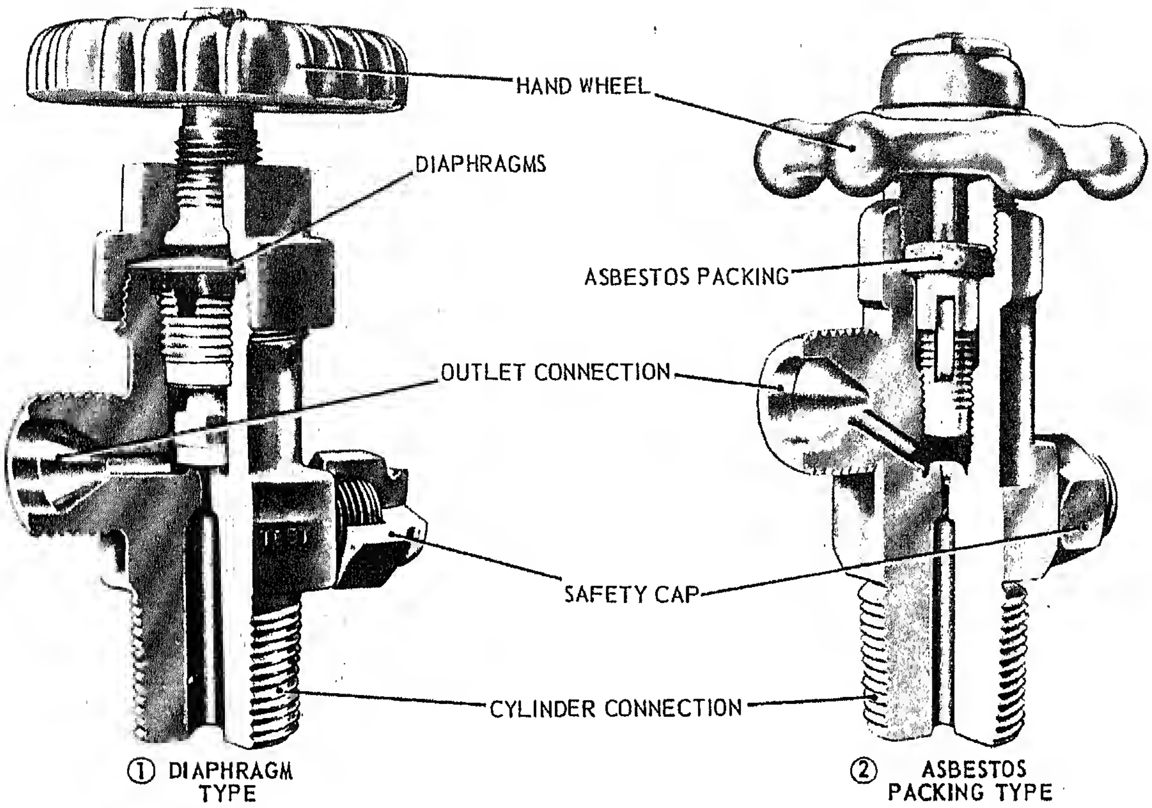


Figure 104. Cutaway views of two types of oxygen cylinder valves.

block off escape parts. When the cylinder and valve are heated above the yield point of fusible metal and the pressure within the cylinder approaches 2,700 to 3,000 psi, the metal begins to flow, the rupture disk ruptures permitting the gas to escape, and the pressure in the cylinder is reduced. This type of device is used on air, argon, helium, hydrogen, nitrogen, and oxygen valves.

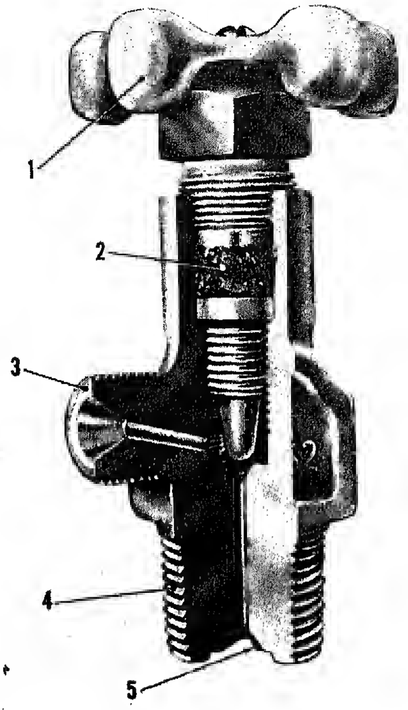
137. Valve Connections and Markings

To prevent the promiscuous use of valves on cylinders which store different types of gases, cylinder valves have characteristic valve-outlet connections as shown in table X, and are also stamped with the name of the gas for which intended. Some valves presently in use may not be marked; these should be stamped by any available means at hand.

Table X. Characteristic Valve Outlet Connections of Cylinder Valves.

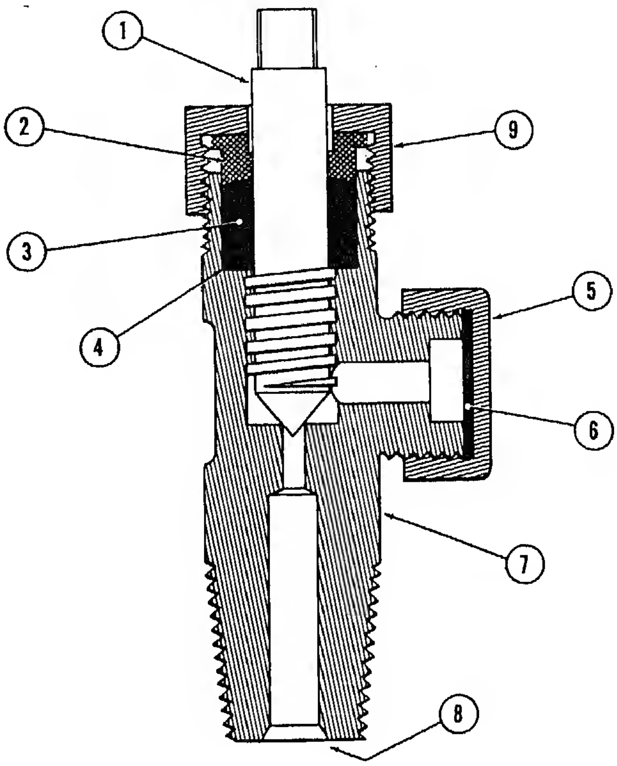
Type of valve	Outside diameter of thread (inches)	Direction of thread	Threads per inch	Type of threads
Oxygen	0.903	Right hand	14	External
Nitrogen (water pumped)	0.903	Right hand	14	External
Nitrogen (oil pumped)	0.903	Left hand	14	External
Acetylene	0.835	Right hand	14	External
Hydrogen	0.830	Left hand	14	External
Helium	0.830	Left hand	14	External
Chlorine	1.0406	Right hand	14	External
Sulfur dioxide	1.0406	Right hand	14	External
Methyl chloride	1.0406	Right hand	14	External
Carbon dioxide	0.825	Right hand	14	External
Freon 12	1.031	Right hand	14	External
Ammonia	⅜*	Right hand	18	Internal

* Ammonia valves have internal outlet connections. Therefore, the inside diameter is given and is usually expressed in fractions.



1 Handwheel
2 Asbestos packing
3 Outlet connection
4 Cylinder connection
5 Wire screen

Figure 105. Cutaway view of an acetylene cylinder valve.



1 Stem
2 Packing gland
3 Ring packing
4 Packing ring
5 Outlet cap
6 Gasket
7 Body
8 Screen
9 Packing nut

Figure 106. Cross sectional view of key-type cylinder valve.

Section IV. PRESSURE REGULATORS

138. Functions

Pressure regulators reduce the pressure of compressed gases from the stored cylinder pressure to the desired working pressure, and maintain this working pressure at a constant rate without material fluctuation. Figure 107 shows a typical pressure regulator attached to an oxygen cylinder. The gages indicating the operating and storage pressure of the gas are an integral part of the regulator. Regulator operation can be more readily understood if the operating principles of two types—the single and the two stage regulators—are discussed.

139. Types

a. Single Stage. In figure 108① the flexible diaphragm is deflected by spring pressure (E), opening the high pressure valve attached to the cylinder, admitting gas to the chamber (F) of the regulator. When the pressure in this chamber is equal to the spring pressure exerted on the flexible diaphragm the high pressure valve will automatically close as the diaphragm tends to straighten. During operation, the operating valve is opened and when the pressure in chamber (F) again falls to a predetermined point, the tension of the spring will again deflect the diaphragm to the left, reopening the valve. Hence, the force tending to open the valve is provided by spring tension and is balanced by the gas pressure on the diaphragm flowing from the high pressure cylinder. When these two forces are equal a constant flow of gas at re-

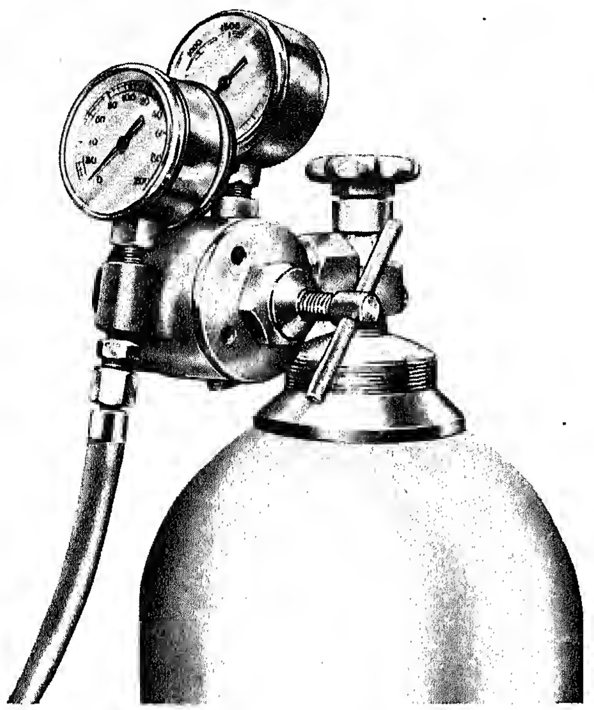


Figure 107. Pressure regulator attached to valve of oxygen cylinder.

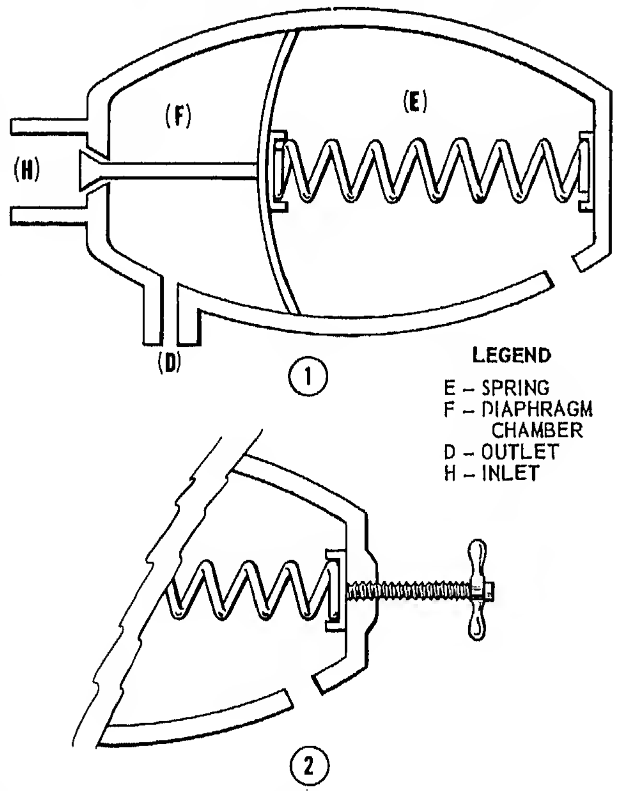
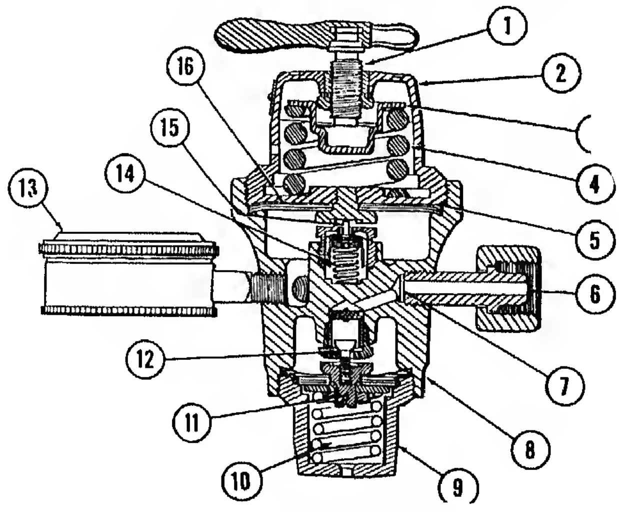


Figure 108. Schematic diagram of pressure regulator.

duced cylinder pressure will result. By replacing the right-hand section of the valve with a spring seat which can be moved through a screw adjustment (2, fig. 108) any variable working pressure can be obtained.

b. Two Stage. If the outlet (D) in figure 108① were connected to the inlet (H) of another regulator, which is equipped with a spring adjustment, a pressure reduction in two stages would result. In the first, the tension of the spring is adjusted so that the high pressure chamber will be a certain fixed amount. The gas then passes from this chamber into a second reducing chamber that is supplied with a screw adjustment. This makes it possible to obtain any desired pressure within the range of the regulator. The details of construction of an oxygen two stage regulator of this type are shown in figure 109. This type is used on single-cylinder or portable manifolds.

c. Gages. In figure 107 a pressure gage of the Bourdon tube type is used to indicate the pressure. This gage works on the principle that an increase in internal pressure on a curved tube will tend to straighten it. Thus, in figure 110① pressure acts equally on every square inch of area in the tube, but since the surface area (A) on the outside of the curve is



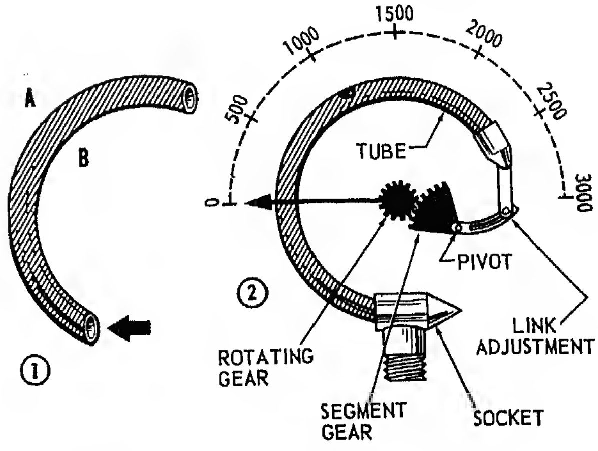
1 Adjusting screw	9 Back cap
2 Bonnet	10 Spring
3 Spring button	11 Seat assembly
4 Spring	12 Nozzle (HP)
5 Diaphragm plate	13 Regulator
6 Inlet	14 Spring
7 Inlet screen	15 Nozzle (LP)
8 Body	16 Diaphragm

Figure 109. Two stage regulator.

greater than the surface area (B) in the shorter radius the force acting on (A) will be greater than the force action on (B). When pressure is applied the tube will straighten until the difference in force is balanced by the elastic resistance of the material composing the tube. Figure 110② shows the working parts of a Bourdon gage. The scale as shown in the figure can be calibrated either in pounds per square inch or in cubic feet of gas. To assure long trouble-free operation on regulators of this type certain operating precautions must be followed:

(1) Cylinder valves must be opened slowly.

(2) The regulator's pressure-adjusting screw should always be loosened whenever the lines are not in use. This prevents a sudden rush of gas into the high- and low-pressure chambers which might result in damage to the regulator or gage mechanism. Moreover, the life of the regulator may be shortened if gas is continually left under pressure in the regulator.



① Principle. ② Schematic diagram.

Figure 110. Bourdon gage.

Section V. SAFETY AND PROTECTIVE MEASURES

140. Introduction

Safety in gas generation requires a thorough understanding of the work being performed and knowledge of each step that must be taken. Safety means exercising good judgment, never trusting to luck, being prepared to cope with unexpected situations, and being alert in following routines. Safety also means remembering the rules and applying them every moment on the job. Gases act according to definite laws, and it is necessary to govern one's actions in generating, storing, handling, and transporting the gases in accordance with these laws. Observing the precautions listed below, which apply to all gas cylinders, will promote safe practice and prevent accidents.

141. Handling Cylinders

a. Do not drop cylinders, and do not permit them to strike each other.

b. Do not use cylinders for rollers or supports, or for any purpose other than to carry the gas for which they are intended. This gas should be clearly indicated by the markings on the cylinder. Never remove the numbers or marks on a cylinder.

c. Cylinders must be filled only by trained troops. One type of filling operation is shown in figure 111.

d. Be careful to protect cylinders from objects that might produce cuts or scratches on the surface of the metal.

e. When a crane is used to lift or move cylinders, provide a cradle or platform similar to that shown in figure 112 to hold the cylinders. A lifting magnet or sling *must not* be used.

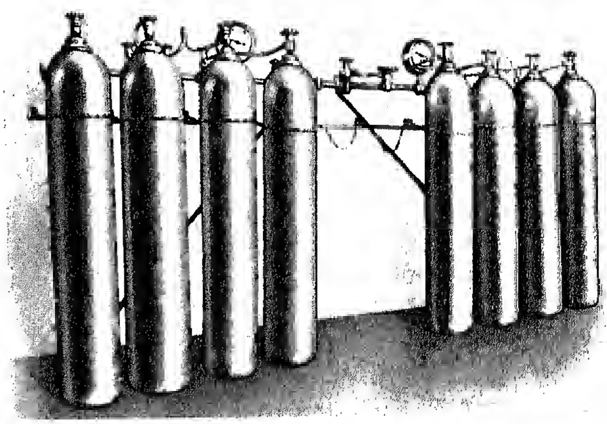


Figure 111. Oxygen cylinders attached to a charging manifold.

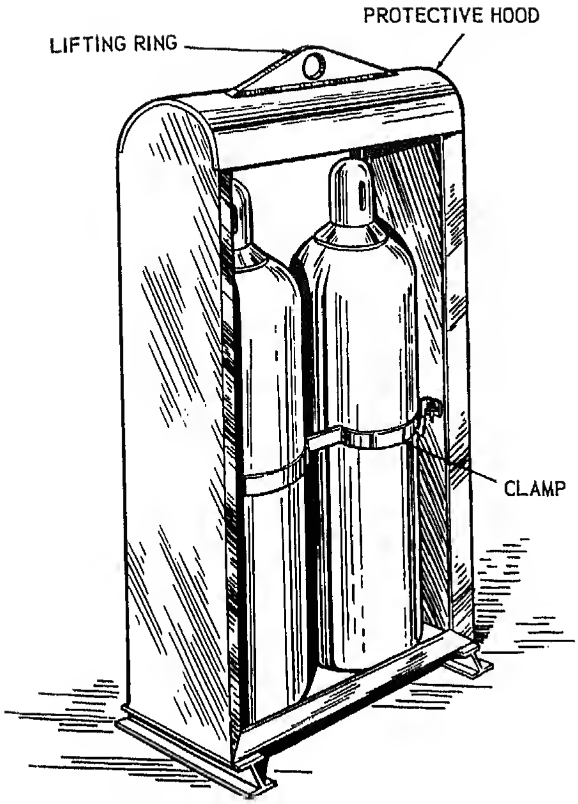


Figure 112. Cradle for lifting cylinders.

f. Securely fasten in position all cylinders while in transit, storage, or use, to prevent them from being jarred or knocked about. See figures 113 and 114 for suggested methods.

Note. The dolly in figures 113 is not normally authorized at present in the Army gas generating units at lower echelons.

g. Carrying cylinders is a two-man job. Do not use oily or greasy gloves when handling. When trucks or other assistance is not available, move the cylinders by tilting and rolling them on the bottom edge. Avoid dragging or sliding.

h. Always close cylinder valves and replace valve caps, when available, before moving cylinders.

i. Never use valve caps, or valves, in lifting cylinders. Never use bars under valves or valve caps to free cylinders frozen or stuck to the ground.

j. When in doubt about the proper handling of a compressed-gas cylinder or its contents, consult the appropriate unit or section head. Further information will be found in TB ENG 39.

142. Storing Cylinders

a. "No smoking" is a must in all cylinder storage or gas generating areas.

b. Never refer to a gas as "air" or "gas." Call it by its proper name.

c. Do not locate cylinder storage areas near highly flammable substances (oil or gasoline), electrical devices (live wires, third rails, or ground wires), damp areas, or salt or other corrosive chemicals or fumes.

d. Protect cylinders against excessive rise and fall of temperature.

e. Protect open-storage areas for cylinders from the direct rays of the sun in summer and accumulations of ice and snow in winter. Extreme cold makes steel brittle. Hence, use utmost care in handling cylinders under these conditions.

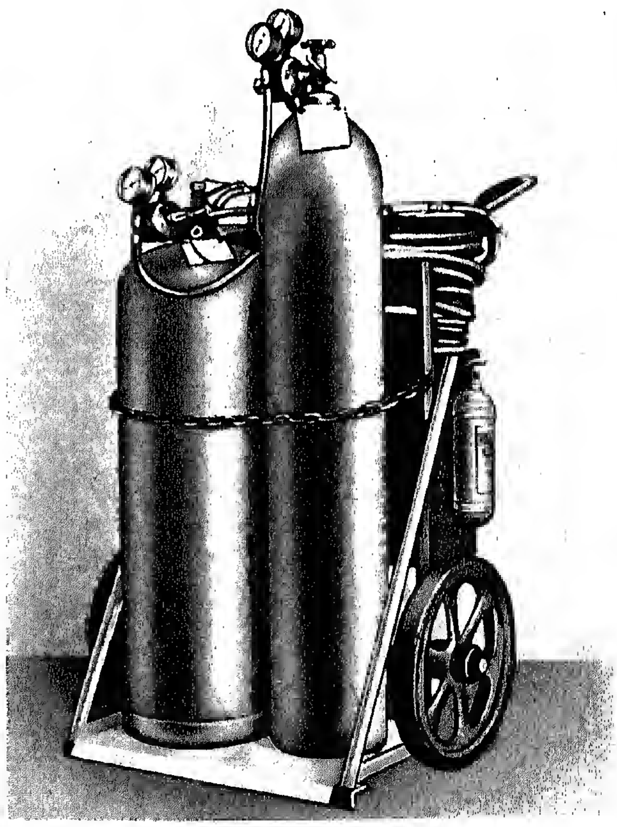


Figure 113. Safe method of transporting cylinders.

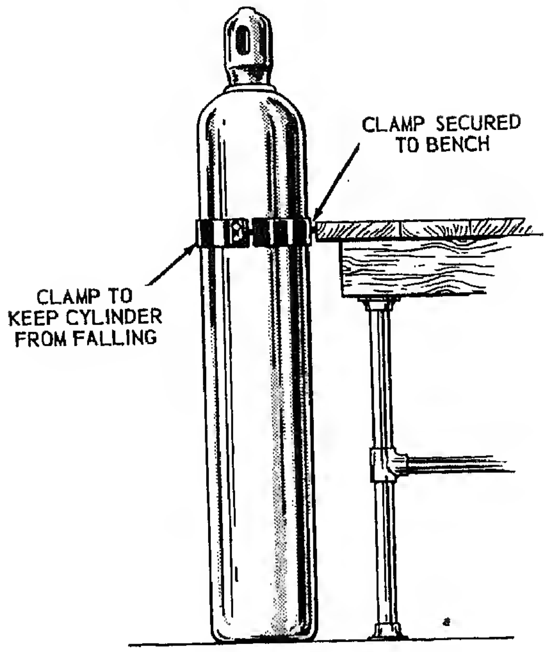


Figure 114. Clamping cylinder in vertical position.

f. Keep closed storage areas well ventilated. This prevents accumulation of explosive or harmful concentrations of gas, and aids in keeping the temperature below the maximum storage temperature of 51° C. (125° F.).

g. Segregate in storage cylinders charged with flammable and nonflammable gases, by means of a fire-resistant partition between the two types (fig. 115). Never store oxygen cylinders in area with acetylene cylinders.

h. Cylinders can either be stored upright or on their sides. When acetylene cylinders are stored on their sides they need special treatment before using. See TB ENG 39 for details.

i. Do not store cylinders in locations where heavy objects may strike or fall on them. This could dent or cut the surface of the metal, or knock off the valve.

j. Treat all cylinders as charged. Store empty cylinders marked EMPTY or MT separately.

k. Always keep valve caps on, when provided. Keep the valves on both full and empty cylinders closed when the cylinders are in storage. Further information will be found in TB ENG 39.

143. Using Cylinders

a. Never use a compressed gas to dust off clothing or ventilate the area.

b. Never locate cylinders where they can be damaged by passing or falling objects, or near stoves, radiators, furnaces, or other hot places where heat, slag, or hot metal might come in contact with them.

c. To promote more rapid discharge and prevent the freezing of gases in cylinders in cold weather, place them inside a building to warm at ordinary room temperatures. Never use direct flame or live steam on any part of the cylinder area.

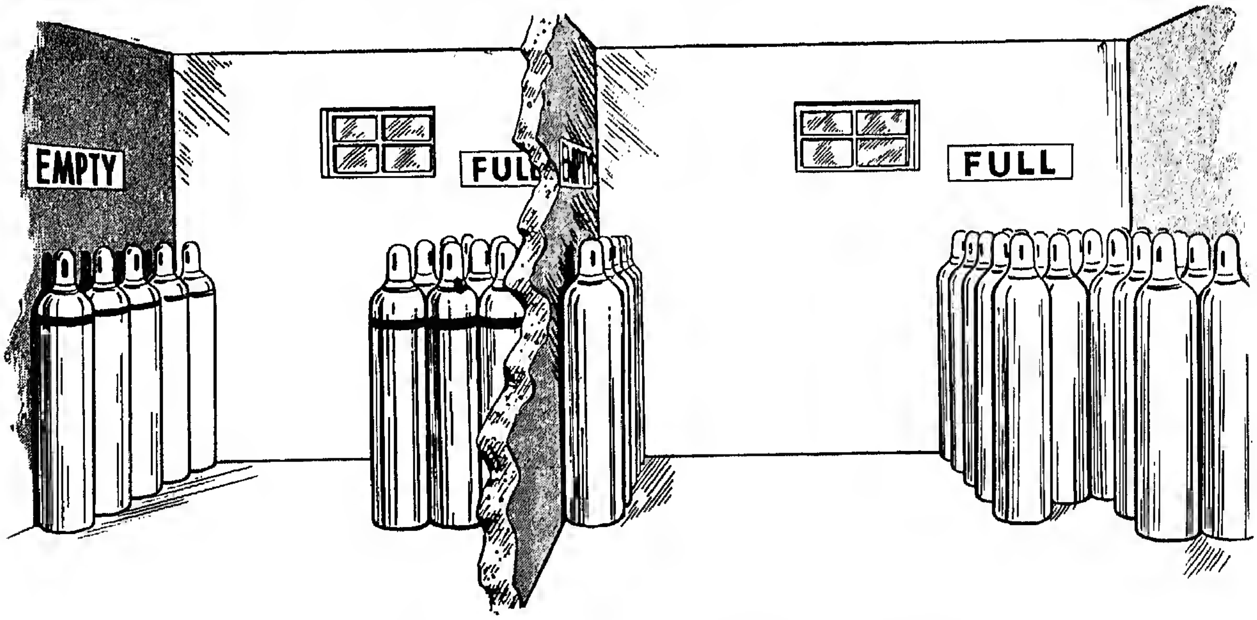


Figure 115. Fire-resistant partition between cylinders containing different gases.

d. Hand wheel- or T-wrench-operated cylinder valves should be easily opened or closed by hand. Never use machinists' wrenches or hammers, since they may damage the valve seat permitting the escape of gas. If a valve is difficult to open, point the valve away from the operator and gradually increase the force.

e. Before connecting a pressure regulator to a cylinder or manifold, quickly open the valve one-fourth of a turn and close it immediately. This clears the particles of dust and dirt from the valve opening. This procedure is called cracking.

f. Never crack an acetylene or flammable gas cylinder near welding work, sparks, or other possible source of ignition.

g. When gas cylinders are being used, reduce cylinder pressure to working pressure through a regulator. An exception to this rule is the use of fire extinguishers filled with carbon dioxide.

h. Check regulator inlet against valve outlet. Never force connections that do not fit.

i. After attaching a regulator and before opening the cylinder valve, release the adjusting screw of the regulator.

j. Do not permit gas to enter the regulator suddenly.

k. Keep cylinder valves fully opened when in use. An exception to this is the acetylene valve which is never opened more than one and one-half turns. Before removing a regulator, close the cylinder valve and then release all gas from the regulator.

l. Hoses should be in good condition and the connections to the hose regulators and other appliances tight. Test connections for leaks by covering with a leak-test solution of soapy water.

m. Do not interchange regulators, pressure gages, hoses, or other appliances with similar equipment for other gases.

n. Cylinders and valves should be repaired or altered only by trained personnel.

o. If a leak is discovered around the valve stem when a valve is opened, close the valve immediately. If this does not stop the leak, move the cylinder outside and tag it as being defective. Keep personnel and sources of ignition away from the area.

p. Never tamper with safety devices in valves or cylinders.

q. If a leak develops at a safety device, move the cylinder outside, open the valve to allow gas to escape slowly, and keep away personnel and sources of ignition.

(1) Drain cylinders containing combustible or toxic gases such as hydrogen, acetylene, or chlorine through pressure regulators, and control their rates of discharge to avoid dangerous accumulations of these gases.

(2) Discharge cylinders containing toxic or irritant gases such as chlorine or sulfur dioxide to the atmosphere only when there will be no hazard to personnel. When draining such cylinders, personnel should be equipped with proper protective clothing, goggles, and breathing masks.

r. Do not stop a leak between the cylinder and regulator by tightening the adjusting nut until the cylinder valve has first been closed and time allowed for the gas to escape.

s. As soon as a cylinder is empty and disconnected, close the valve and replace the outlet to prevent damage to the threads of the outlet connection.

144. Precautions for Refrigerant Gases

General precautions to be taken in using, storing, and transporting refrigerant-gas cylinders are the same as those discussed in paragraphs 140 to 143. However, certain special precautions apply only to refrigerant gases. They are as follows:

a. Avoid drawing liquid refrigerant or oil into a cylinder when discharging the contents. Close the valve immediately after the cylinder has been emptied.

b. As soon as a cylinder is emptied, the valve closed, and the cylinder disconnected from refrigerating system, place the outlet-connection cap on the valve outlet connection to prevent dirt from entering and damaging the threads. Carefully screw the valve protection caps in place before the cylinder is placed in storage.

c. Never connect a cylinder to a refrigerating system except when the system is being charged or drained.

145. Fire Fighting

See paragraph 52.

Section VI. CYLINDER, CYLINDER VALVE, AND REGULATOR SERVICING AND MAINTENANCE

146. Introduction

Compressed gas cylinders frequently carry industrial gases under high and dangerous pressures. These cylinders are the links in the Army's worldwide chain of production, distribution, and consumption of vital and frequently flammable and explosive gases. It is important that each cylinder be fit to do its job, to carry the correct gas, to withstand rough handling and exposure, and to provide a foolproof source of clearly identified gas to the men who finally use it in their work. It is not the job of the consumer to see if the cylinders are properly marked and in good condition. This must be done by the men who handle and refill the cylinders.

147. Cylinder Servicing and Maintenance

a. Determination of Type of Cylinder. As was described in paragraphs 129 through 134, a cylinder may be identified by its color code, type of valve, Department of the Army symbol, and I.C.C. marking.

b. Hydrostatic Test Date. As outlined in paragraph 132, I.C.C. regulations require a test every 5 years of all high-pressure cylinders. The date of test or retest should be stamped on the shoulder of the cylinder directly opposite the I.C.C. and Department of the Army symbol. For example, the stamping 3–54 means the last test was made in March 1954.

c. Smell Test. This test should be made with caution, but is one way of making sure that the gas in the cylinder is the same as indicated by the identification markings. The valve is opened slightly, and some of the escaping gas trapped in the cupped hands and brought cautiously to the nose. This test, of course, is useful only if the personnel can identify odors of the various types of gases. These have been outlined in table VIII.

d. Valve Check. As was pointed out in paragraphs 135 and 137 various gages have different types of noninterchangeable valves. Each valve in use in the Army should have the name of the gas for which it is designed indented on a side or flat part of the valve. Valves should be appropriately stamped for specific use and obsolete valves replaced.

(1) Carefully check valves for damage. Check to see that they are not jammed in the closed or opened position. If the body of the valve is dented, recheck the cylinder for dents around the shoulder.

(2) Inspect the outlet-connection thread for stripped or flattened threads. Damaged connection threads will in turn damage the threads of the pressure regulators. Any bend or dent in a valve body, no matter how small, is cause for replacement.

(3) Do not loosen or remove the safety nut unless necessary. Inspect safety nuts containing fusible metal visually to determine if fusible metal is still intact. Inspect the threads in the nut and its seat in the valve for damage, and make repairs or replacements as necessary.

e. Inspect for Grease and Oil. Do not fill cylinders with oxygen if there is any trace of grease or oil present. Cylinders having a large amount of these impurities on or in them must be washed or stripped in a caustic solution.

f. Stripping Cylinders. Washing or stripping cylinders consists of cleaning them inside and out with a hot mixture of 15 percent caustic potash and water. If a stripping bath is available, submerge the cylinder in it. In any case, the cylinder should be filled with the cleaning solution and then agitated by shaking or rolling. after cleaning, remove all traces of the caustic by washing the cylinders in clear water. Where possible, also steam the cylinder after the clear water washing. A wire brush can be used at this time to remove paint from the cylinder. In washing (or stripping) cylinders, however, several precautions must be taken.

(1) Never place the valves near the stripping bath. Under no conditions should any hot caustic be splashed on them.

(2) Wear goggles and gloves while working around the stripping bath.

(3) Keep hands and tools free of oil and grease.

(4) Do not use this method for cylinders containing oxygen for breathing unless a special drying apparatus is available.

g. Inspection for Rust Spots. Use a rubber insulated and caged trouble light to inspect the interior of each cylinder for rust. If rust is present, remove it by shotting or chaining. Shotting consists of putting several pounds of shot in the cylinder and rolling it. Two wooden rollers driven by an electric motor provide a method of revolving the cylinder. If no such device is available, the cylinders may be rolled along a level surface protected by softwood stringers. Chaining uses short length of chain instead of shot. The chains are attached to a rod which is long enough to reach the bottom of the cylinder. One end of this rod is machined to fit into the chuck of a portable electric hand drill. By moving this rotating rod and chain device in and out of the cylinder, rusted areas can be worked down to bright metal.

h. Inspection for Loose Neck Rings. If the threads of the neck ring are worn and rusted away, install a new ring. Neck rings which have not become worn and which are simply loose on the cylinder can usually be repaired. First remove the valves from the cylinder in order to prevent their damage, and then peen the joint which the ring makes with the cylinder until the ring makes a tight fit. After peening, screw a cap tightly on the neck ring, and then remove it to insure that the ring is tightly fitted to the cylinder and cannot move.

i. Inspection for Dents. Inspect the outer surface of the cylinder, including the base, for dents. If a dent is found, place a straightedge along the cylinder and measure the distance from the bottom of the dent to the straightedge. If the dent is over a half inch in depth, set the cylinder aside for disposal.

j. Cuts, Gouges or Digs. Cuts, gouges, or digs in a cylinder are deformations caused by contact with a sharp object in such a way as to cut into or upset the metal of the cylinder, decreasing the wall thickness at that point.

k. Corrosion or Pitting. Corrosion or pitting in a cylinder results in a loss of wall thickness and is caused by chemical action. Several kinds of pitting or corrosion, as defined below, must be considered. If corrosion or pitting is so extreme that the cylinder does not meet I.C.C. specifications, the cylinder is discarded.

(1) *Isolated pitting.* Isolated pits of small size do not effectively weaken the cylinder wall but indicate possible complete penetration and leakage. Since the pitting is isolated the original wall is essentially intact.

(2) *Line corrosion.* When pits are not isolated but are connected or nearly connected to others in a narrow band or line, such a pattern is termed line corrosion. This condition is more serious than isolated pitting.

(3) *General corrosion.* General corrosion is that which covers considerable surface areas of the cylinder. Such corrosion reduces the structural strength. It is often difficult to measure or estimate the depth of general corrosion because direct comparison with the original wall cannot be made. General corrosion is often accompanied by pitting.

l. Inspection for Correct Color Code. If any cylinder is not painted the correct color code, do not fill it with any gas until it has been correctly painted. The correct color codes were outlined briefly in paragraph 131. Mil Std 101–A, as outlined in table XV of appendix II, covers the specific coloring in greater detail. A definite standing operating procedure for painting cylinders should be organized in order that no errors are made and no precautions overlooked. Before painting, wire brush rust spots, paint blisters, and corroded spots down to bright metal. During the painting process, recheck the cylinders for dents, weld spots, and rust pits. Take special care to keep the cylinder valve free of paint.

m. Acetylene Cylinders. Also give acetylene cylinders careful inspection when repainting them. Because acetylene cylinders do not require the I.C.C. 5-year test, there is more danger that they will be retained in use without

adequate inspection of the cylinder, valves, fusible plugs, and asbestos packing. The filler or asbestos packing in a cylinder lessens the chance of acetone being carried out with the acetylene. The filler should come to the bottom of the valve, but it should not interfere with the valve threading. Over a period of time it may pack down or shred out and leave a pocket in which dangerous quantities of pure acetylene could collect. It is checked by removing the valve and then sighting or feeling it. The packing and porous filler should not be loose, nor should there be an appreciable space between the valve and the packing. If carbon is noticed on the valve body, the valve is removed and the interior of the cylinder is examined for burned filler. If the filler is burned, the cylinder should be discarded.

148. Valve Regulator

a. Valve Removal. If any of the above cylinder defects are noted and require repair, or the quantity or content of the gas in the cylinder is questionable, relieve the pressure in the cylinder and remove the valve. In removing a cylinder valve, use a vise and a valve removal wrench of the type shown in figure 116. If the valve is defective and is to be repaired, an empty cylinder makes a convenient holding fixture when working on the valve. Valve defects can easily be remedied by replacing the valve or dismantling it and cleaning, repairing, or replacing the damaged parts. The valve is then reassembled.

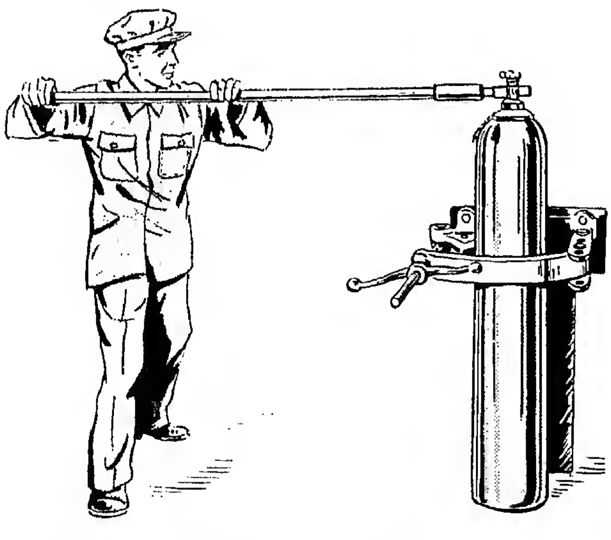


Figure 116. Cylinder vise and valve removal wrench.

b. Valve Leaks. Valve leaks are either in the body or the packing. If in the body they may be due to foreign matter in the valve seat, scoring of the valve seat, or distortion of the valve body. When foreign matter causes a valve leak, this is sometimes corrected by partially opening and closing the valve to blow out the foreign material. A scored valve seat can either be reground, or a new seat provided. A distorted valve part will probably have to be replaced.

c. Packing Leaks. If a packed valve leaks through the stuffing box, the box requires repacking or the gland nut may be loose and needs to be tightened. Caution must be used in this operation since the action may cause the stem to stick or require undue pressure in operating. If the stem does stick, the adjustment screw over the stuffing box should be relieved to slightly release the packing. The stem may also stick because it is rusty or dirty or bent or broken. If the stem is bent or broken or the valve threads are stripped or burred, the stem should be replaced.

d. Valve Replacement. Use only the correct tools in disassembling or reassembling the valve, and make sure it is in the open position when replaced. Since the majority of valve manufacturers have parts peculiar to their own design, make sure the repair or replacement parts used are correct. When valves are replaced in a cylinder or the threads on the valves are sealed, a compound of litharge and water can be used for sealing the threads. Valves can also be sealed in a cylinder by means of a lead-foil cap. All cylinder valves should be inspected regularly as a preventive maintenance measure.

e. Acetylene Valves. Valves used in acetylene cylinders are equipped with screens at the valve inlet. If difficulty is experienced when filling the cylinder with acetone before recharging it, either the cylinder valve is blocked and should be replaced or the screen is clogged. In the latter case, the valve should be removed as outlined above, and the screen cleaned and replaced. During the process the acetone well should also be examined for obstructions, and if these are present, the filler in the well should also be removed and replaced.

149. Pressure Regulator Servicing and Maintenance

a. General. Pressure regulator equipment used on cylinders must be inspected at frequent intervals by competent personnel. Some of the common troubles which may occur with regulators are creep, relief-disk rupture, or leakage.

b. Safety First. Under no circumstances should oil or grease be applied to a regulator. This equipment does not require lubrication, and oil or grease may violently ignite, causing a fire or explosion, if they come in contact with oxygen under pressure.

c. Regulator Creep. Regulator creep is indicated on the working pressure gage by a pressure buildup after the system is closed. This is a continuous pressure increase and may be remedied by changing the valve seat or stem of the regulator. If the gage hand will not go back to the pin when the pressure is released, replace the gage by a new one.

d. Relief Disk. If the safety relief disk ruptures, install a new one immediately.

e. Leaky Regulator. Always maintain a gastight connection between the regulator and the cylinder. If the cylinder valve has not been cracked, dirt may be left in the valve opening which might mar the regulator inlet nipple seat or prevent a gastight connection from being made between the regulator and the cylinder valve. If the connection leaks when a reasonable force has been used in tightening the nut, close the cylinder valve, remove the regulator, and clean both the inside of the cylinder-valve seat and the regulator inlet nipple seat. If excessive force is used in tightening the connection, the seats may be marred, or the threads and nuts may become so distorted that the regulator will not fit any cylinder and cannot be used. Never tighten a leaky connection between a regulator and cylinder without first closing the cylinder valve and waiting awhile for the gas in the connection to dissipate.

APPENDIX I

REFERENCES

AR 700–8120–1	Safe Handling, Storing, Shipping, Use, and Disposal of Compressed Gas Cylinders
AR 701–5	Logistics Responsibilities in Gas Generating Equipment
AR 701–3655	Logistics Responsibilities, Gas Generating Equipment
AR 743–505	Limited Storage of Engineer Mechanical Equipment
AR 750–5	Organization, Policies, and Responsibilities for Maintenance
TM 5–687	Repair and Utilities, Fire Protection Equipment and Appliances
TM 5–3655–Series	(on oxygen, nitrogen, carbon dioxide, and hydrogen production)
TM 5–5040	Generator, Gas (Acetylene), Sight Feed
TM 5–5047	Generator, Gas (Acetylene), Marquette
TM 5–6630–200–Series	(on Hydrocarbon)
TM 5–8120–Series	(on Liquid Oxygen Storage Tanks and Gas Cylinders)
TM 10–279	Protective Clothing for Missile Fuel Handlers
TM 38–230	Preservation, Packaging, and Packing of Military Supplies and Equipment
TM 38–750	The Army Equipment Record System and Procedures
TM 38–750–1	Maintenance Management: Field Command Procedures
TB 5–351–1	Liquid Oxygen and Nitrogen
TB 5–5047–1	Generator, Gas (Acetylene)
TB ENG 39	Safe Handling of Compressed Gases
TB ENG 362	Improved Maintenance Procedures for Hydrogen and Carbon Dioxide Generators
SB 5–111	Supply of DA Approved Fire Extinguishers to Army Troop Users
Mil Std 101–A	Color Code for Pipelines and Compressed Gas Cylinders
Mil–T–7003	Trichlorethylene Stabilized, Degreasing
TMCP–750	Sight Feed Generator

Table XI. Thermometer Scales

Centigrade	Fahrenheit	Kelvin (or Absolute)	Rankine	Concrete scale (mostly approximate)
−273	−459.6	0	0	−256° C., hydrogen freezes
−250	−418.0	+23	+42	−250° C., hydrogen boils
−225	−373.0	+48	+87	−214° C., nitrogen freezes
−200	−328.0	+73	+132	−200° C., temperature of liquid air
−190	−310.0	+83	+150	−196° C., nitrogen boils
−180	−292.0	+93	+168	−183° C., (1 atm.) oxygen boils
−170	−274.0	+103	+186	
−160	−256.0	+113	+204	
−150	−238.0	+123	+232	−147° C., critical temperature of nitrogen
−140	−220.0	+133	+240	−140° C., critical temperature of air
−130	−202.0	+143	+258	
−120	−184.0	+153	+276	−119° C., critical temperature of oxygen

Table XI. Thermometer Scales—Continued

Centigrade	Fahrenheit	Kelvin (or Absolute)	Rankine	Concrete scale (mostly approximate)
−110	−166.0	+163	+294	
−100	−148.0	+173	+312	
−90	−130.0	+183	+330	
−80	−112.0	+193	+348	−79° C., carbon dioxide forms dry ice
−70	−94.0	+203	+366	
−60	−76.0	+213	+384	−56° C., (73 atm) melting pt. of CO_2
−50	−58.0	+223	+402	
−40	−40.0	+233	+420	
−30	−22.0	+243	+438	−29.8° C., freon vaporizes and liquefies
−20	−4.0	+253	+456	
−10	+14.0	+263	+474	
0	+32.0	+273.0	+492	0° C., freezing point of water
+10	+50.0	+283.0	+510	
+20	+68.0	+293.0	+528	
+30	+86.0	+303.0	+546	28.5° C., calcium chloride ($CaCl_2$ + $6H_2O$) melts (see also 719° C.)
+40	+104.0	+313.0	+564	31° C., critical temperature of carbon dioxide
+50	+122.0	+323.0	+582	38° C., ignition temperature of fuel oil
+60	+140.0	+333.0	+600	51.7° C., max. storage temperature of acetylene
+70	+158.0	+343.0	+618	56° C., boiling point of acetone
+80	+176.0	+353.0	+636	
+90	+194.0	+363.0	+654	
+100	+212.0	+373.0	+672	100° C., water boils
+200	+392.0	+473.0	+852	144° C., MEA and CO_2 separate
+300	+572.0	+573.0	+1032	280° C., ignition temperature of regular gasoline
+400	+752.0	+673.0	+1212	
+500	+932.0	+773.0	+1392	555° C., ignition temperature of methanol 650° C., combustible temperature of ammonia
+700	+1292.0	+973.0	+1752	700° C., ignition temperature of acetone
+1000	+1832.0	+1273.0	+2292	719° C., calcium chloride ($CaCl_2$) melts (see also 28.5° C.)
+1500	+2732.0	+1773.0	+3192	
+2000	+3632.0	+2273.0	+4092	2000°–2100° C., calcium oxide and coke are fused to form calcium carbide and carbon monoxide

APPENDIX II

TABLES

Table XII. Acetylene Generator Pressure Settings

Generator pressure (pounds per square inch)	Compressor output (cubic feet per hour)
5	625
6	650
7	675
8	700
9	725
10	750

Table XIII. Maximum Allowable Charge of Acetylene for Cylinders

Note. Values given in pounds and ounces.

Circumference in inches	Length in inches												
	7 to 9	9 to 11	11 to 13	13 to 15	15 to 17	17 to 19	19 to 21	21 to 23	23 to 25	25 to 27	27 to 29	29 to 31	31 to 33
12½ to 13½	0–4	0–6	0–7	0–9	0–10	0–11	-----	-----	-----	-----	-----	-----	-----
13½ to 15	0–5	0–7	0–8	0–10	0–12	0–14	-----	-----	-----	-----	-----	-----	-----
15 to 16½	0–8	0–10	0–12	0–14	1–0	1–2	1–4	-----	-----	-----	-----	-----	-----
16½ to 18	0–9	0–12	0–15	1–2	1–4	1–7	1–10	1–13	-----	-----	-----	-----	-----
18 to 19¾	0–13	1–0	1–3	1–7	1–10	1–13	2–0	2–3	-----	-----	-----	-----	-----
19¾ to 21½	1–0	1–3	1–6	1–9	1–13	2–0	2–3	2–6	2–9	-----	-----	-----	-----
21½ to 22¾	-----	1–5	1–9	1–14	2–2	2–6	2–10	2–14	3–2	3–6	-----	-----	-----
22¾ to 24½	-----	-----	1–13	2–2	2–7	2–12	3–1	3–6	3–11	4–0	4–5	-----	-----
24½ to 26	-----	-----	-----	2–7	2–13	3–3	3–8	3–14	4–4	4–9	4–15	5–4	-----
26 to 27½	-----	-----	-----	-----	3–3	3–10	4–0	4–7	4–13	5–3	5–10	6–0	6–7

Circumference in inches	Length in inches												
	17 to 19	19 to 21	21 to 23	23 to 25	25 to 27	27 to 29	29 to 31	31 to 33	33 to 35	35 to 37	37 to 39	39 to 41	
27½ to 29	4–1	4–8	5–0	5–7	5–14	6–5	6–13	7–4	7–11	8–2	-----	-----	
29 to 30¾	4–9	5–1	5–8	6–1	6–9	7–2	7–10	8–2	8–10	9–2	9–10	-----	
30¾ to 32¼	-----	5–10	6–3	6–12	7–5	7–15	8–8	9–1	9–10	10–3	10–12	11–5	
32¼ to 33¾	-----	6–4	6–14	7–8	8–2	8–12	9–6	10–0	10–10	11–4	11–14	12–8	
33¾ to 35¼	-----	-----	7–10	8–5	9–0	9–11	10–6	11–1	11–12	12–7	13–2	13–13	
35¼ to 37	-----	-----	-----	9–1	9–14	10–10	11–6	12–2	12–14	13–10	14–6	15–2	
37 to 39¼	-----	-----	-----	9–15	10–12	11–9	12–7	13–4	14–1	14–14	15–12	16–9	

Circumference in inches	Length in inches												
	25 to 27	27 to 29	29 to 31	31 to 33	33 to 35	35 to 37	37 to 39	39 to 41	41 to 43	43 to 45	45 to 47		
32¼ to 33¾	-----	-----	-----	-----	-----	-----	-----	-----	13–2	-----	-----		
33¾ to 35¼	-----	-----	-----	-----	-----	-----	-----	-----	14–8	-----	-----		
35¼ to 37	-----	-----	-----	-----	-----	-----	-----	-----	15–14	16–11	-----		
37 to 39¼	-----	-----	-----	-----	-----	-----	-----	-----	17–6	18–3	19–1		
39¼ to 40¾	11–11	12–10	13–8	14–7	15–5	16–4	17–2	18–0	18–15	19–13	20–12		
40¾ to 42½	-----	13–11	14–11	15–10	16–10	17–10	18–9	19–9	20–9	21–8	22–8		

Table XIII. Maximum Allowable Charges of Acetylene for Cylinders—Continued

Circumference in inches	Length in inches											
	29 to 31	31 to 33	33 to 35	35 to 37	37 to 39	39 to 41	41 to 43	43 to 45	45 to 47	47 to 49	49 to 51	51 to 53
39¼ to 40¾	-----	-----	-----	-----	-----	-----	-----	-----	-----	21–10	22–9	-----
40¾ to 42½	-----	-----	-----	-----	-----	-----	-----	-----	-----	23–8	24–7	-----
42½ to 44	15–14	16–15	18–0	19–1	20–2	21–2	22–3	23–4	24–5	25–6	26–7	27–8
44 to 45½	17–2	18–4	19–6	20–9	21–11	22–13	23–15	25–2	26–4	27–6	28–8	29–11
45½ to 47	-----	19–10	20–14	22–1	23–5	24–9	25–12	27–0	28–3	29–7	30–11	31–14
47 to 48¾	-----	21–1	22–6	23–11	25–0	26–5	27–10	28–15	30–4	31–9	32–14	43–3
48¾ to 50¼	-----	-----	23–15	25–6	26–12	28–3	29–9	31–0	32–6	33–13	35–3	36–10
50¼ to 51¾	-----	-----	25–9	27–1	28–9	30–1	31–9	33–1	34–9	36–1	37–10	39–2
51¾ to 53¼	-----	-----	-----	28–13	30–7	32–1	33–10	35–4	36–14	38–7	40–1	41–11

Circumference in inches	Length in inches		
	53 to 55	55 to 57	57 to 59
45½ to 47	33–2	-----	-----
47 to 48¾	35–8	36–13	-----
48¾ to 50¼	38–0	39–6	40–12
50¼ to 51¾	40–10	42–2	43–10
51¾ to 53¼	43–4	44–14	46–8

Table XIV. Prefix and Suffix Designation Serial Numbers Appearing on Cylinders

High-pressure cylinders made under Interstate Commerce Commission Specification 3A for service pressure 1,800 pounds per square inch and higher.

Prefix	Approximate water capacity	Size of cylinder
A	35 cu in	2¹⁵⁄₁₆ in. inside diam x 7⅜ in. high (approx)
C	85 cu in	3⅛ in. inside diam x 13 in. high (approx)
D	175 cu in	3¹⁵⁄₁₆ in. inside diam x 16¾ in. high (approx)
DE	235 cu in	3¹⁵⁄₁₆ in. inside diam x 21¼ in. high (approx)
E	290 cu in	3¹⁵⁄₁₆ in. inside diam x 25¾ in. high (approx)
EE	325 cu in	4⅛ in. inside diam x 26 in. high (approx)
EF	450 cu in	5 in. inside diam x 26 in. high (approx)
F	940 cu in	5 in. inside diam x 51 in. high (approx)
FG	1,350 cu in	6⅝ in. inside diam x 43 in. high (approx)
G	2,360 cu in	8 in. inside diam x 51 in. high (approx)
H	2,650 cu in	8½ in. inside diam x 51 in. high (approx)
J	----------	Internal capacity 2,750 to 4,100 cu in.
JC	----------	For 75 lb of carbon dioxide
L	----------	Internal capacity over 4,100 cu in.
LC	----------	For 100 lb of carbon dioxide

High-pressure cylinders made under Interstate Commerce Commission specification 3E.

Serial numbers will not be used. Cylinders will be in all cases not over 1.99 inches outside diameter and not over 12 inches long, exclusive of neck.

Acetylene cylinders made under Interstate Commerce Commission specification 8. Prefix W required in all cases. Suffix letters required in all cases depend on rated (approximate) gas capacity.

Suffix	*Rated gas capacity*
B	50 cu ft
C	100 cu ft
H	150 cu ft
J	250 cu ft
K	300 cu ft

Low pressure cylinders made under Interstate Commerce Commission specifications 3A, 3B, 3C, 4, 4A, 4B, and 4C for service pressure not over 480 lb per sq in.

Prefix	*ICC Specification marked on cylinder*
KC	ICC—3A 150
KF	ICC—3A 240
KJ	ICC—3A 300
KM	ICC—3A 480
NC	ICC—3B 150

NF	ICC—3B 240
NJ	ICC—3B 300
NM	ICC—3B 480
OA	ICC—3C 90
OC	ICC—3C 150
OF	ICC—3C 240
O	ICC—3C 300
P	ICC—3D 480
RC	ICC—4A 150
RF	ICC—4A 240
RJ	ICC—4A 300
RM	ICC—4A 480
S	ICC—4
TC	ICC—4B 150
TF	ICC—4B 240
TJ	ICC—4B 300
UA	ICC—4C 90
UC	ICC—4C 150
UF	ICC—4C 240
UJ	ICC—4C 300

Suffix letters are used dependent on the water capacity of cylinders.

Suffix	*Water capacity of cylinder (lb)*
None	Below 4
A	4 to 7.99
B	8 to 11.99
C	12 to 15.99
D	16 to 19.99
E	20 to 39.99
F	40 to 59.99
G	60 to 79.99
H	80 to 99.99
K	100 to 129.99
M	130 to 159.99
P	160 to 229.99
S	230 to 319.99
U	320 to 399.99
W	400 to 499.99
Y	500 to 749.99
Z	750 to 1000.00

Table XV. Military Standard 101A—Color Code for Compressed Gas Cylinders and Pipelines

Title	Top A	Band B	Band C	Body
Acetylene	Yellow	Yellow	Yellow	Yellow
Acrolein	Yellow	Brown	Black	Brown
Aerosol insecticide	Buff	Buff	Buff	Buff
Air, oil pumped	Black	Green	Green	Black
Air, water pumped	Black	Green	Black	Black
Ammonia	Brown	Yellow	Orange	Orange
Argon, oil pumped	Gray	White	White	Gray
Argon, water pumped	Gray	White	Gray	Gray
Boron trichloride	Gray	Brown	Gray	Brown
Boron trifluoride	Gray	Brown	Brown	Brown
Bromoacetone	Brown	Black	Black	Brown
Bromochloromethane	Buff	Gray	Buff	Buff
Bromochloromethane (fire only)	Red	Gray	Red	Red
Bromotrifluoromethane	Orange	White	Gray	Orange
Bromotrifluoromethane (fire only)	Red	White	Gray	Red
Butadiene	Yellow	White	Buff	Buff
Carbon dioxide	Gray	Gray	Gray	Gray
Carbon dioxide (fire only)	Red	Red	Red	Red
Carbon monoxide	Yellow	Brown	Brown	Brown
Chloroacetone	Black	Brown	Black	Brown
Chlorine	Brown	Brown	Brown	Brown
Chlorine trifluoride	Brown	Green	Brown	Brown
Chloropicrin	Brown	Orange	Orange	Brown
Cyanogen	Yellow	Brown	Yellow	Brown
Cyclopropane, medical	Orange	Yellow	Blue	Blue
Cyclopropane, medical	Orange		Chromium plated	
Dibromodifluoromethane	Buff	White	Buff	Buff
Dibromodifluoromethane (fire only)	Red	White	Red	Red
Difluorochloroethane	Gray	Yellow	Yellow	Orange
Difluoroethane	Gray	Yellow	Orange	Orange
Dimethylamine, anhydrous	Yellow	Blue	White	Buff
Dimethylether	Yellow	Brown	Buff	Buff
Dispersant, Dichlorodifluoromethane-Difluoroethane Mix	Buff	Gray	Gray	Buff

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Table XV. Military Standard 101A—Color Code for Compressed Gas Cylinders and Pipelines—Continued

Title	Top A	Band B	Band C	Body
Ethane	Yellow	Blue	Yellow	Yellow
Ethyl chloride	Buff	Blue	Yellow	Buff
Ethyl nitrite	Yellow	Buff	Buff	Buff
Ethylamine, anhydrous	Yellow	Blue	Blue	Buff
Ethylene, industrial	Blue	Yellow	Buff	Buff
Ethylene, medical	Yellow	Blue	Blue	Blue
Ethylene oxide	Yellow	Blue	Buff	Buff
F–11, Trichlorofluoromethane	Orange	Orange	Orange	Orange
F–12, Dichlorodifluoromethane	Orange	Orange	Orange	Orange
F–13, Chlorotrifluoromethane	Orange	Orange	Orange	Orange
F–21, Dichlorofluoromethane	Orange	Orange	Orange	Orange
F–22, Chlorodifluoromethane	Orange	Orange	Orange	Orange
F–113, Trichlorotrifluoroethane	Orange	Orange	Orange	Orange
F–114, Dichlorotetrafluoroethane	Orange	Orange	Orange	Orange
F–124A, Chlorotetrafluoroethane	Orange	Orange	Orange	Orange
Fluorine	Brown	Green	Green	Brown
Fumigant, Carbon dioxide-Ethylene oxide	Buff	Blue	Buff	Buff
Helium, oil free or medical	Buff	Gray	Gray	Gray
Helium, oil pumped	Gray	Orange	Gray	Gray
Helium-Oxygen	Buff[1]	White[2]	Green	Green
Hydrogen	Yellow	Black	Yellow	Yellow
Hydrogen bromide	Black	Brown	Brown	Brown
Hydrogen chloride, anhydrous	Brown	White	Brown	Brown
Hydrogen cyanide, anhydrous	Yellow	Brown	White	Brown
Hydrogen fluoride, anhydrous	Green	Brown	Brown	Brown
Hydrogen sulfide	Brown	Yellow	Brown	Brown
Krypton, oil pumped	Gray	Buff	Buff	Gray
Krypton, water pumped	Gray	Buff	Gray	Gray
Manufactured Gas—(Specify) Coal, oil, water, producer, etc.	Brown	Yellow	Yellow	Yellow
Methane	Yellow	White	Yellow	Yellow
Methylamine	Yellow	Brown	Yellow	Buff
Methyl bromide	Brown	Black	Brown	Brown
Methyl bromide (fire only)	Red	Brown	Red	Red
Methyl chloride	Yellow	Brown	Orange	Orange
Methyl mercaptan	Brown	Yellow	Yellow	Brown
Methyl sulfide	Yellow	Brown	Buff	Brown
Methylene chloride	Gray	Blue	Orange	Orange
Natural gas	Yellow	Brown	Yellow	Yellow
Neon, oil pumped	White	Buff	Gray	Gray
Neon, water pumped	White	Buff	Buff	Gray
Nickel carbonyl	Yellow	White	Yellow	Brown
Nitric oxide	Brown	Buff	Brown	Brown
Nitrogen dioxide	Brown	Buff	Buff	Brown
Nitrogen, oil pumped	Gray	Black	Gray	Gray
Nitrogen, water pumped	Gray	Black	Black	Gray
Nitrosyl chloride	Brown	White	White	Brown
Nitrous oxide	Blue	Blue	Blue	Blue
Oxygen, medical	White	Green	Green	Green
Oxygen, aviator's	Green	White	Green	Green
Oxygen	Green	Green	Green	Green
Oxygen-Carbon dioxide	Gray[1]	White[2]	Green	Green
Petroleum Gas—(specify) Acetogen, Butane, Butane-Propane, Butene–1, Cyclopropane, Isobutane, Isobutylene, Neopetane, Propane, etc.	Yellow	Orange	Yellow	Yellow

[1] A′ or A″ for medical gas mixtures.

[2] B′ or B″ for medical gas mixtures.

Table XV. Military Standard 101A—Color Code for Compressed Gas Cylinders and Pipelines—Continued

Title	Top A	Band B	Band C	Body
Phenylcarbylamine chloride	Brown	Gray	Gray	Brown
Phosgene	Brown	Orange	Brown	Brown
Propylene	Yellow	Gray	Buff	Buff
Sulfur dioxide	Brown	Gray	Brown	Brown
Sulfur hexafluoride	Gray	White	Black	Gray
Tetrafluoroethylene, inhibited	Buff	White	White	Buff
Trimethylamine, anhydrous	Yellow	Blue	Orange	Buff
Vinyl bromide	Buff	Blue	Blue	Buff
Vinyl chloride	Yellow	Orange	Buff	Buff
Vinyl methyl ether, inhibited	Yellow	Black	Buff	Buff
Xenon, oil pumped	White	Black	Black	Gray
Xenon, water pumped	White	Black	Gray	Gray

GLOSSARY

Γhis brief glossary is intended as a quick re-
w of some of the terms used in this manual.
ok in the index and in the chapters covering
ated subjects for a lead to other terms not
ed here, or for more information than given
e.

solute temperature—Temperature measured n degrees Klevino or Rankine (from abso- ute zero).

solute zero—The temperature at which all nolecular action is believed to cease (—273.16°C. or —459.69°F.).

sorption—Assimilation; such as a gas dis- olved by a liquid.

stone—A colorless, odorous liquid; boiling oint 56°C. (133°F.); mixing in all propor- ions with water, alcohol, or ether, and used s a solvent for many organic compounds.

olein—A colorless liquid of sharp odor, used o give a warning smell to otherwise odorless ases.

orption—The adhesion, in an extremely thin yer, of the molecules of gases, dissolved ubstances, or liquids, to the surfaces of solid odies. Generally speaking, liquids absorb ases, solids adsorb gases.

bient Temperature—The temperature of the edium surrounding an object (usually room mperature).

ydrous—Dry, lacking in water.

hyxia—Unconsciousness caused by defici- ncy of oxygen and excess of carbon dioxide the blood.

rdon-tube gage — A pressure-measuring ge having a closed circular tube, fixed at e end, which tends to straighten out when ternal pressure is applied, thus actuating e dial mechanism which is connected to the ovable end of the tube.

le's Law—At constant temperature, pres- re and volume of a gas vary inversely; increase pressure and volume decreases, expand volume and pressure decreases.

Butane—A flammable, gaseous hydrocarbon, used for heating and cooling purposes. It liquefies easily and is stored and transported as 'liquefied petroleum gas."

Cardox unit—A portable unit used for the storage and transportation of liquid and solid carbon dioxide.

Catalyst—A substance which will accelerate the chemical reaction between two or more other substances without itself being changed.

Caustic—The term normally applied to sodium and potassium hydroxide; an agent that "burns off" dirt and impurities.

CC—Cubic centimeters, also cm^3.

Centigrade—A temperature scale on which, under standard conditions of pressure (14.7 psia), the boiling point of water is designated as 100° and the freezing point at 0°. The interval between these 2 points is divided into 100 equal parts.

Charles' Law—When the pressure is kept constant, the volume of a gas is proportional to its absolute temperature. When a gas is heated, it expands; when it is cooled, it contracts.

Chemical characteristics—The chemical properties of a substance; for example, a piece of steel has physical properties such as hardness, springiness, and expansibility; its chemical properties are those such as rusting in air, burning in oxygen, and corroding in acid.

Conductivity — Degree to which a substance transmits heat, electricity, or other forms of energy.

Cracking (gas or oil)—A process in which the complex hydrocarbons composing petroleum or other similar oils are broken up by heat and pressure into lighter hydrocarbons. Cracking is used in producing commercial gasoline, and in enriching illuminating gas.

Critical point—The point at which vapor and liquid states of a substance become indistinguishable.

Critical pressure — The pressure required to liquefy a gas at the critical temperature.

Critical temperature—The critical temperature of a gas is that temperature above which it is impossible to liquefy a gas.

Destructive distillation—The process of decomposing a substance (as wood, coal, bone) in a closed vessel by means of heat, and collecting the volatile products given off.

Displacement — The volume or weight of a fluid, as water, displaced by a floating body, as by a ship. The weight of the displaced fluid is equal to that of the displacing body if the body floats.

Electrolysis—Chemical decomposition of a substance by electric current.

Fahrenheit—A temperature scale on which, under standard conditions of pressure (14.7 psia), the boiling point of water is designated as 212° and the freezing point at 32° above zero of the scale.

Flue gases—Gases remaining after combustion has taken place.

Fractional distillation—Process used to separate the constituents of a mixture through differences in their boiling points.

Frangible—Breakable.

Freon—A name applied to a group of easily liquefied gases used as refrigerants.

GPM—Gallons per minute.

Henry's Law (absorption of gases)—The greater the pressure, the more a gas dissolves in a solution; the amount so dissolved is directly proportional to the pressure.

Hydrocarbon—A compound containing only hydrogen and carbon, as acetylene, benzene, etc.

Hydrostatic — Relating to the pressure and equilibrium of liquids.

Inert — Chemically inactive; not combining with other chemicals.

Kelvin—A temperature scale on which 0°C. is 273° K. (Degrees Kelvin).

Kinetic—Of, pertaining to, or due to motion.

Kinetic theory of matter—The theory that the minute particles of which substances are composed are in vigorous motion.

Latent heat—The heat given up or absorbed by a body when a change of state takes place and no change of temperature is involved.

Liquefaction—Process by which a gas is liquefied by an increase in pressure and reduction in temperature.

Louvers—A slatted grille or panel for ventilation.

Manometer—An instrument which measures gas pressures by balancing fluid heads.

Methanol—CH_3OH; simplest of organic alcohols. It is a combination of carbon monoxide and hydrogen under high pressure and a copper oxide catalyst.

Monoethanolamine (MEA) — A solvent compound used to collect carbon dioxide from flue gases by absorption.

Monolithic—Used in connection with the filler materials in acetylene tanks, indicates that the porous stone, charcoal, asbestos, or other materials are the same throughout the entire tank.

Nitriding—The introduction of nitrogen into the outer surface of steel parts to give an extremely hard, wear-resistant case.

Perfect gas (ideal gas)—A gas that conforms exactly to Boyle's Law and Charles' Law. No known gas does so. In many practical applications, adjustments for each gas must be made.

Physical characteristics—See chemical characteristics.

Pigtail (connections)—A flexible-tube connection leading from a gas cylinder to a filling connection on gasplant equipment.

Propane—A heavy gaseous hydrocarbon, of the saturated hydrocarbon series occurring naturally dissolved in crude petroleum; used for heat and cooking.

PSIA—Pounds per square inch absolute.

PSIG—Pounds per square inch gage.

Pungent—Sharp, piercing, painful taste or smell.

Raschig rings—Short lengths of tubing with lengths equal to the diameter; when packed

into absorption towers they afford an intimate intermingling of gas and liquid.

flux accumulator — Tank in which dilute MEA solution and raw CO_2 gas, from the reactivator condensers, are gravity separated.

ica gel—A compound used as an adsorbent to ;ake up moisture.

Solvent—Substance (usually liquid) that dissolves something else.

Sublimation—To pass directly from a solid to a gaseous state.

Surge Drum—Vessel to receive excess MEA from the boiler when a surge occurs in the boiler.

Tare Weight—Weight of an empty container.

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By Order of the Secretary of the Army:

EARLE G. WHEELER,
General, United States Army,
Chief of Staff.

Official:

J. C. LAMBERT,
Major General, United States Army,
The Adjutant General.

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USAARMBD (5)
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6–300 (2)
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NG: State AG (4); Units—Same as Active Army except allowance is one copy to each unit.
USAR: Same as Active Army except allowance is one copy to each unit.
For explanation of abbreviations used, see AR 320–50.